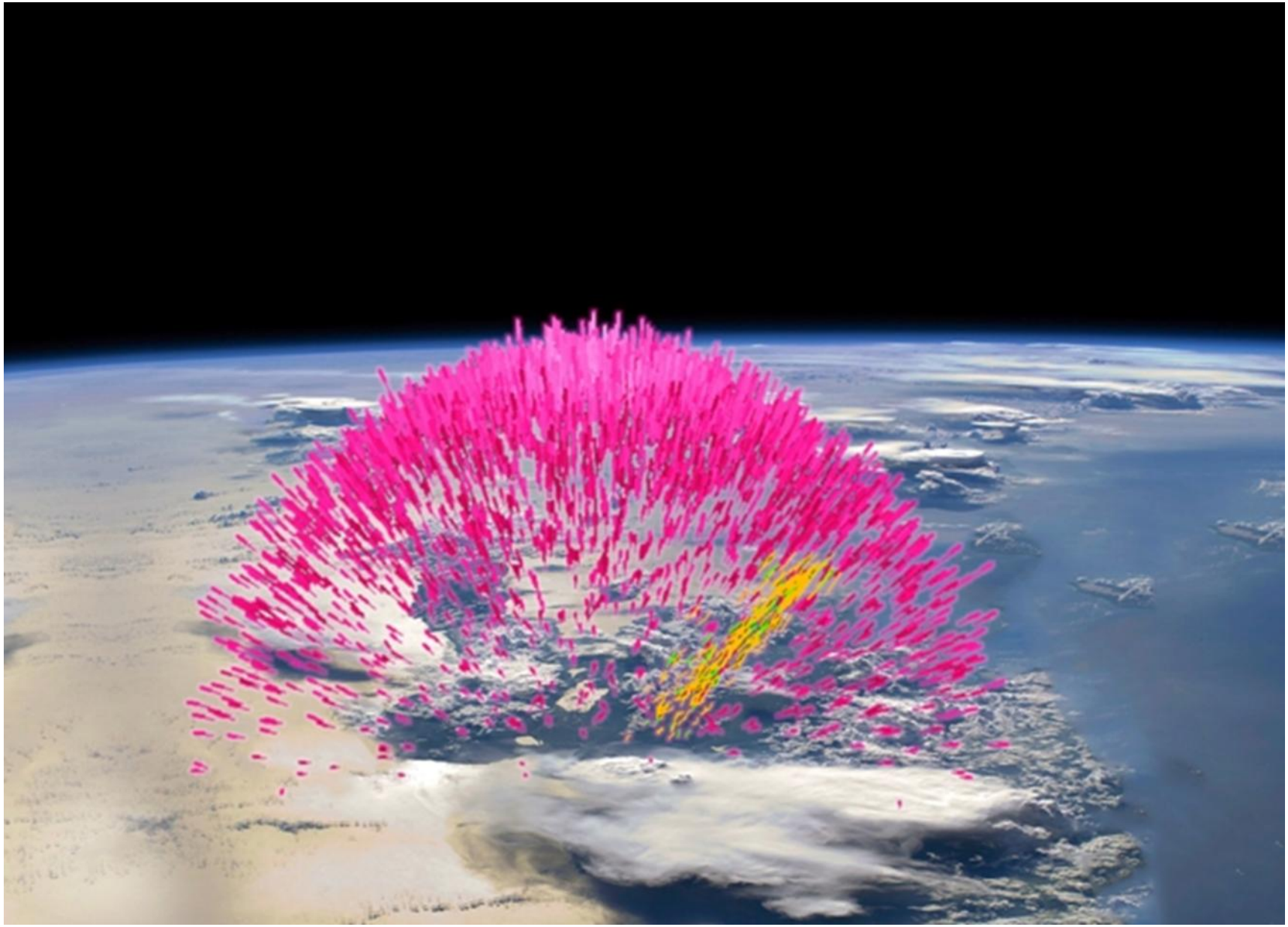
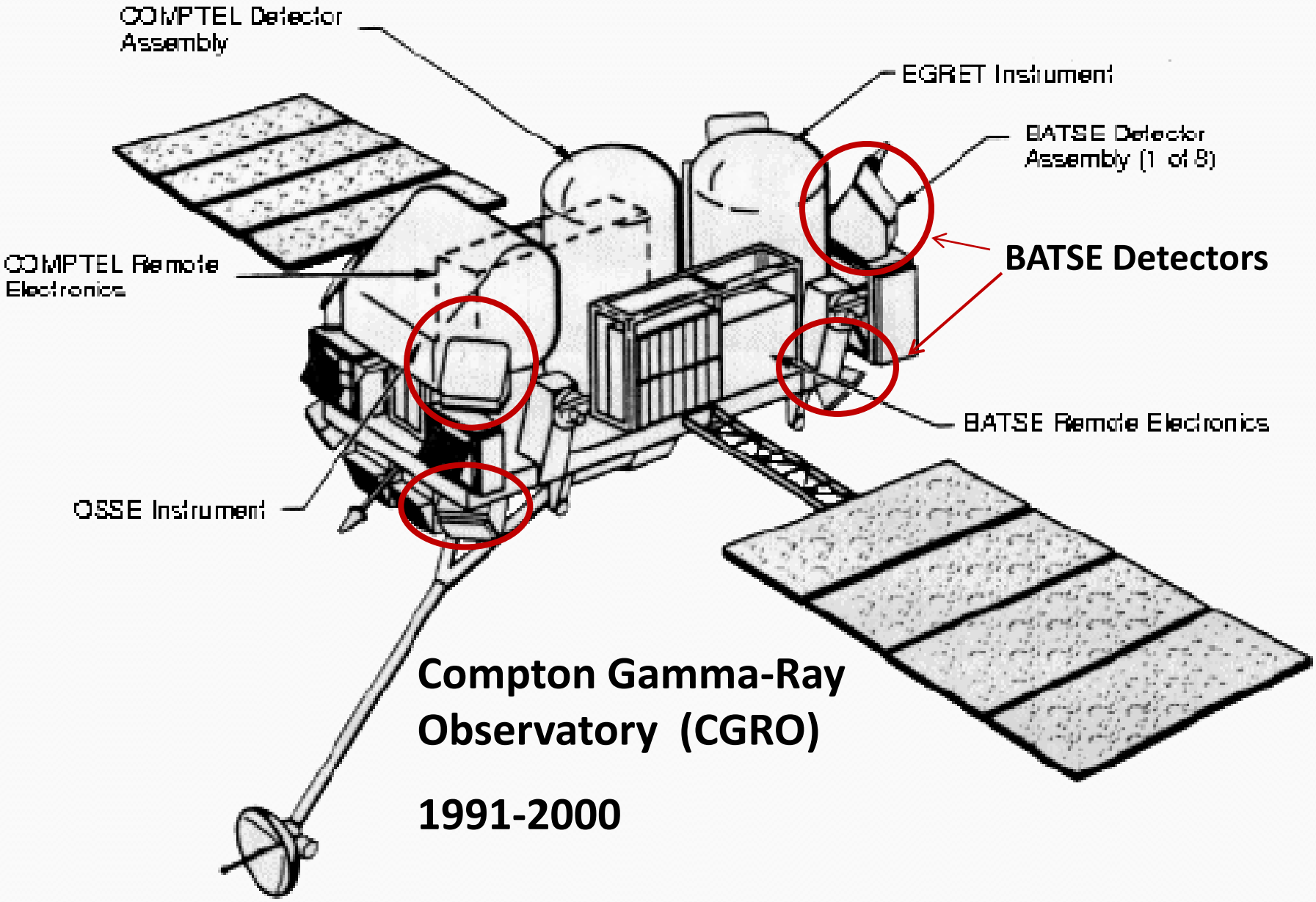
Terrestrial Gamma-Ray Flashes (TGFs) above Thunderstorms

Gerald J. (Jerry) Fishman
NASA-Marshall Space Flight Center
Huntsville, AL USA

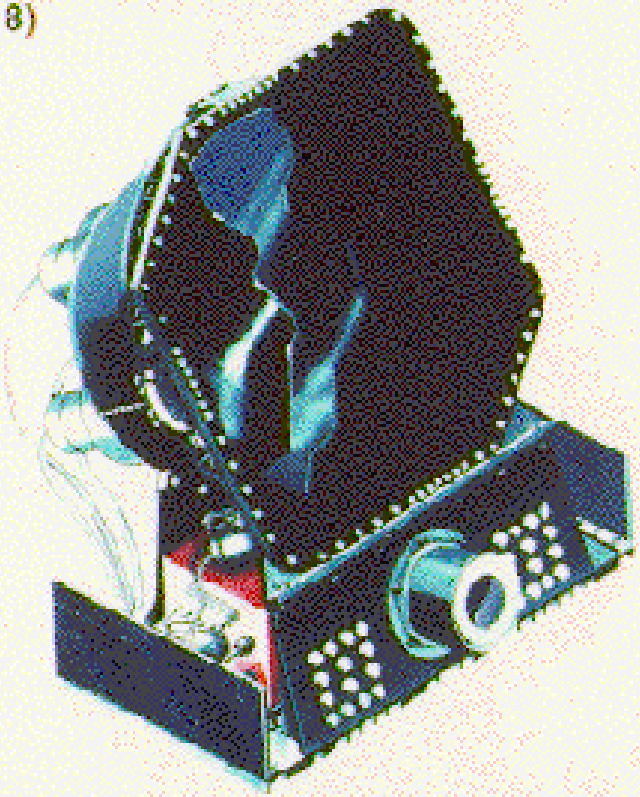
Physics Dept.
University of Missouri
March 20, 2012

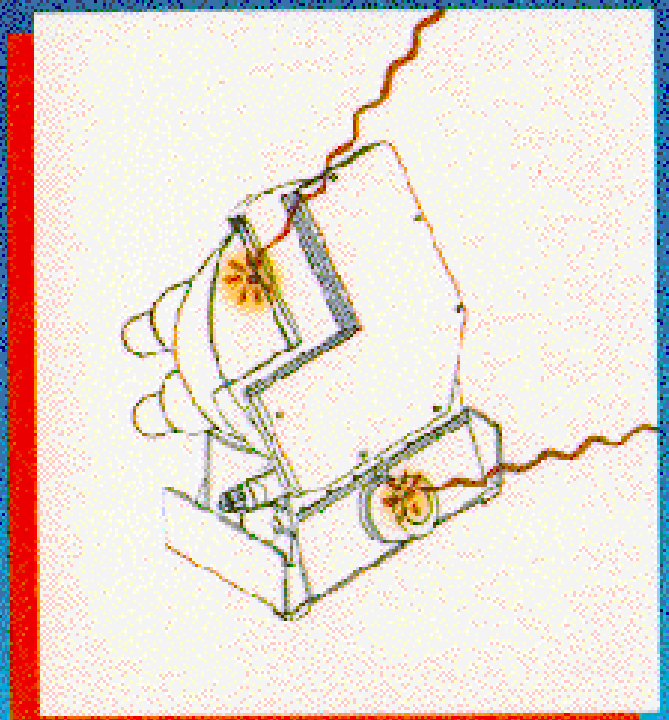



COMPTEL Detector Assembly
EGRET Instrument
BATSE Detector Assembly (1 of 8)
BATSE Detectors
COMPTEL Remote Electronics
BATSE Remote Electronics
OSSE Instrument
Compton Gamma-Ray Observatory (CGRO)
1991-2000

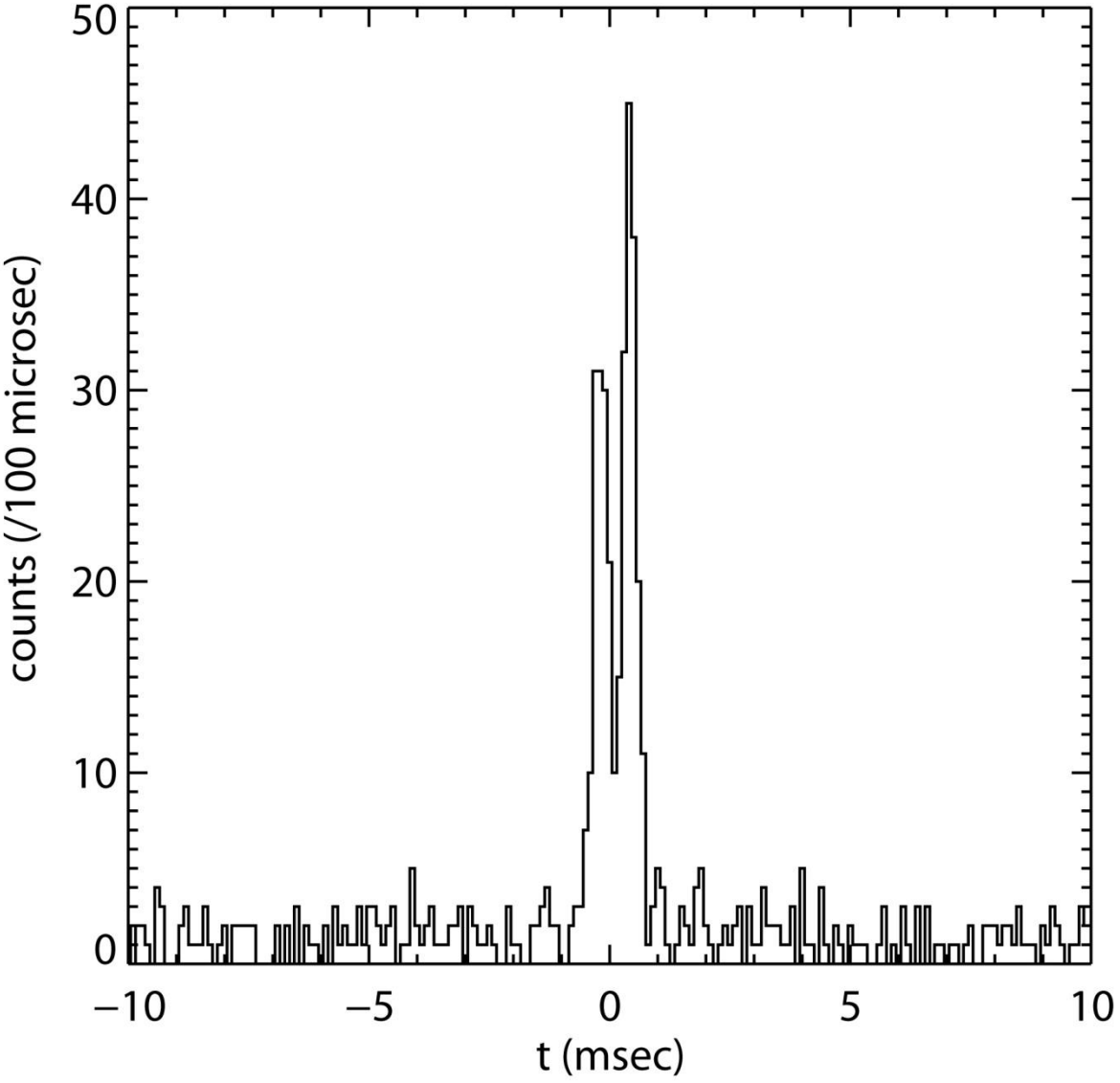
Burst and Transient Source Experiment (BATSE)

BATSE
DETECTOR MODULE
(1 OF 8)





CGRO/BATSE Terrestrial Gamma-ray Flash (TGF)
(Fishman *et al*. 1994)



http://www.batse.msfc.nasa.gov/batse/tgf/

SCIENCE **- v. 264, p. 1313, May 27, 1994**

Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin

Detectors aboard the Compton Gamma Ray Observatory have observed an unexplained terrestrial phenomenon: brief, intense flashes of gamma rays. These flashes must originate in the atmosphere at altitudes above at least 30 kilometers in order to escape atmospheric absorption and reach the orbiting detectors. At least a dozen such events have been

SPACE AGE ARCHAEOLOGY • MEMORY AND THE MIND'S EYE • FOOD, SEX AND INSECTS

SCIENTIFIC AMERICAN

AUGUST 1997 $4.95

AGE AND ENERGY
HOW SUBTLE MUTATIONS IN CELLULAR DYNAMOS SLOWLY WEAKEN THE BRAIN AND MUSCLES

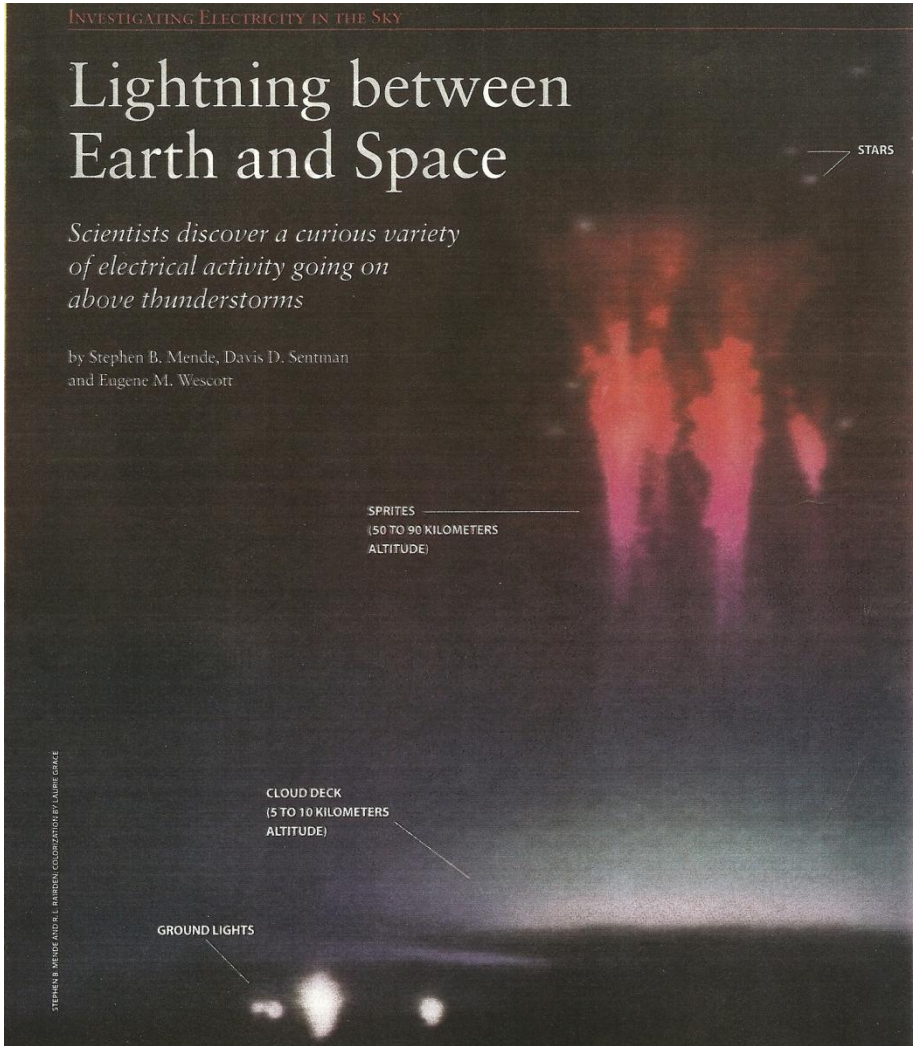
Bolts arc between clouds and the earth, but also from clouds toward space

COPYRIGHT © 1997 BY SCIENTIFIC AMERICAN, INC. ALL RIGHTS RESERVED

Lightning between Earth and Space

Scientists discover a curious variety of electrical activity going on above thunderstorms

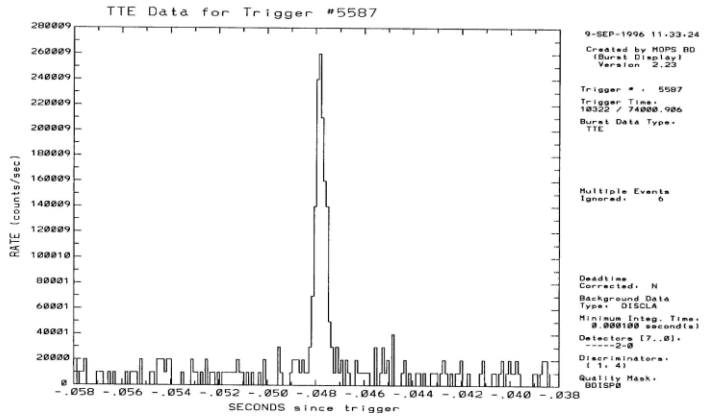
by Stephen B. Mende, Davis D. Sentman and Eugene M. Wescott

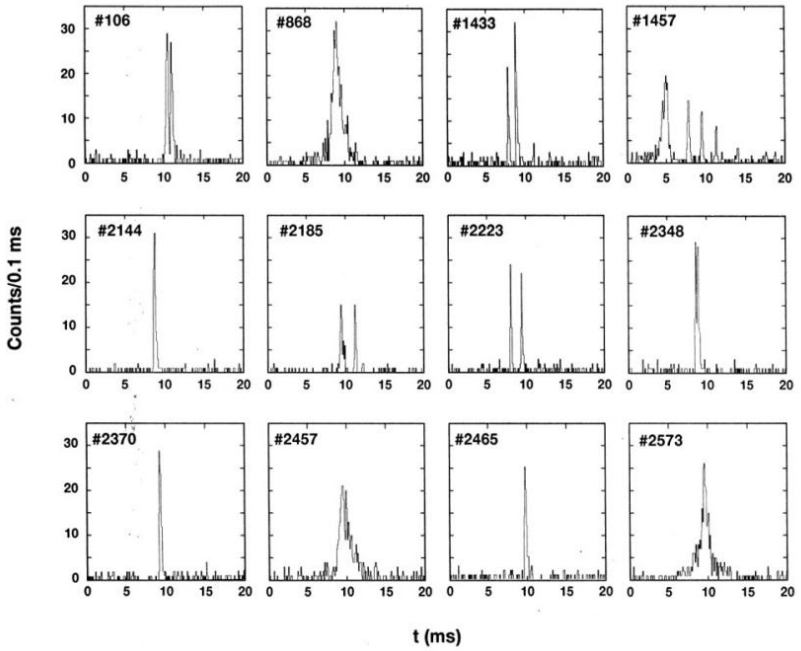


SPRITES are high-altitude luminous flashes that take place above thunderstorms in a part of the atmosphere called the mesosphere. Although sprites are usually rare, some storms can spawn them frequently. Typically the upper parts of clouds are charged positively and the lower parts negatively. Most often, it is the negative base of the cloud that flashes to the ground. But at times the upper, positive part can discharge directly to the earth, producing a lightning flash of exceptional intensity. About one out of 20 such positive cloud-to-ground lightning bolts are sufficiently energetic that they spawn sprites. These examples, recorded from the ground with a monochromatic video camera, have been colorized to match a color image obtained from an aircraft.

BATSE TGFs:

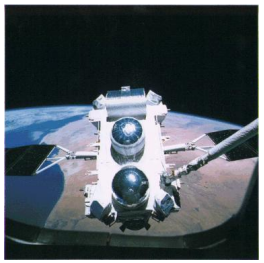
- Determined rough spectral properties (extremely energetic)
- Associated with thunderstorms
- Observed 78 in 9 years

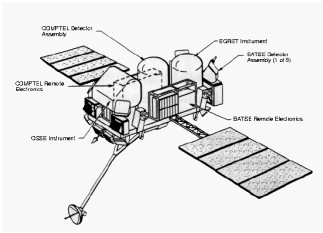




Four Orbiting Spacecraft Have Observed TGFs:

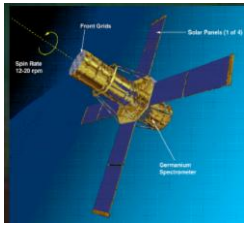
BATSE on the Compton Gamma-ray Observatory





- Discovered TGFs ; publ. in 1994
- Operational 1991-2000

RHESSI - Solar Spectroscopy Spacecraft



- Comprehensive TGF Observations
- On-line Catalog of TGFs; still in-orbit

AGILE

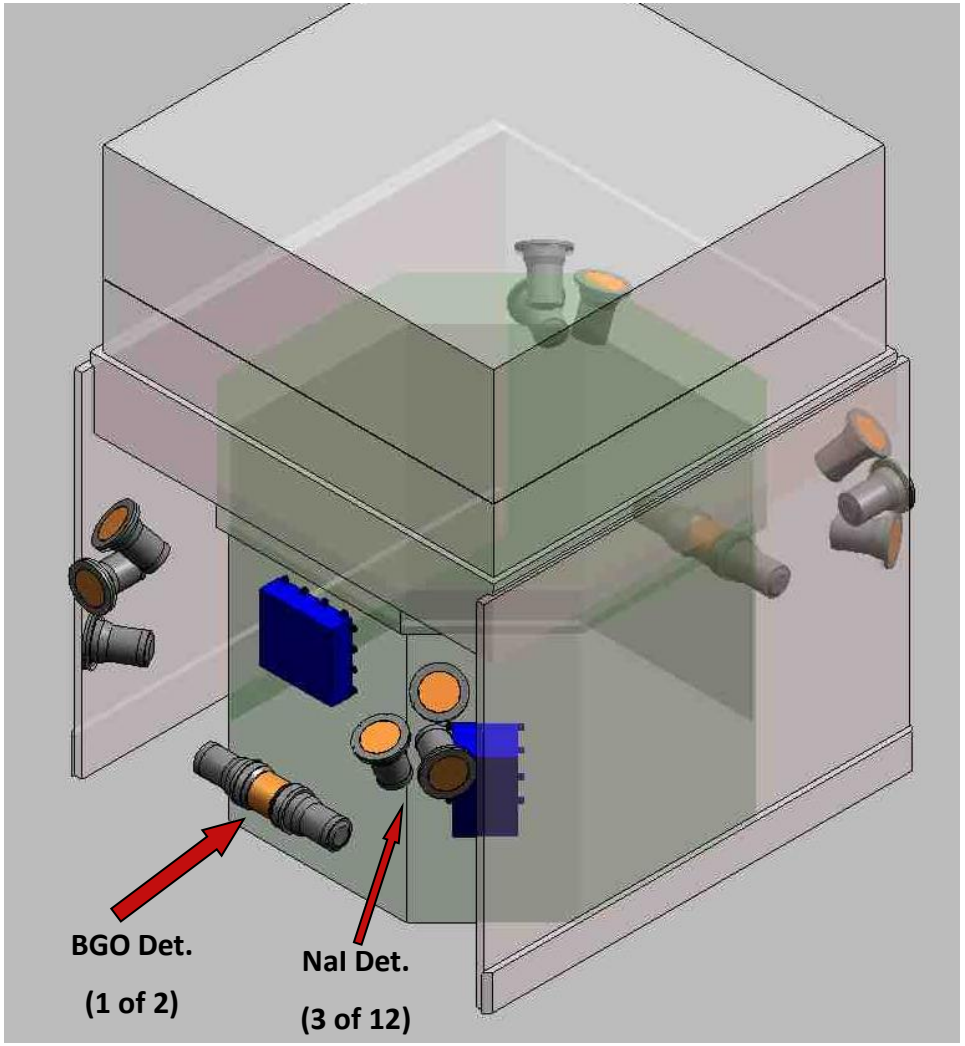
- Italian Gamma-ray Astronomy Mission
- Detects TGFs at high energies; still operational

Fermi Gamma-ray Space Telescope

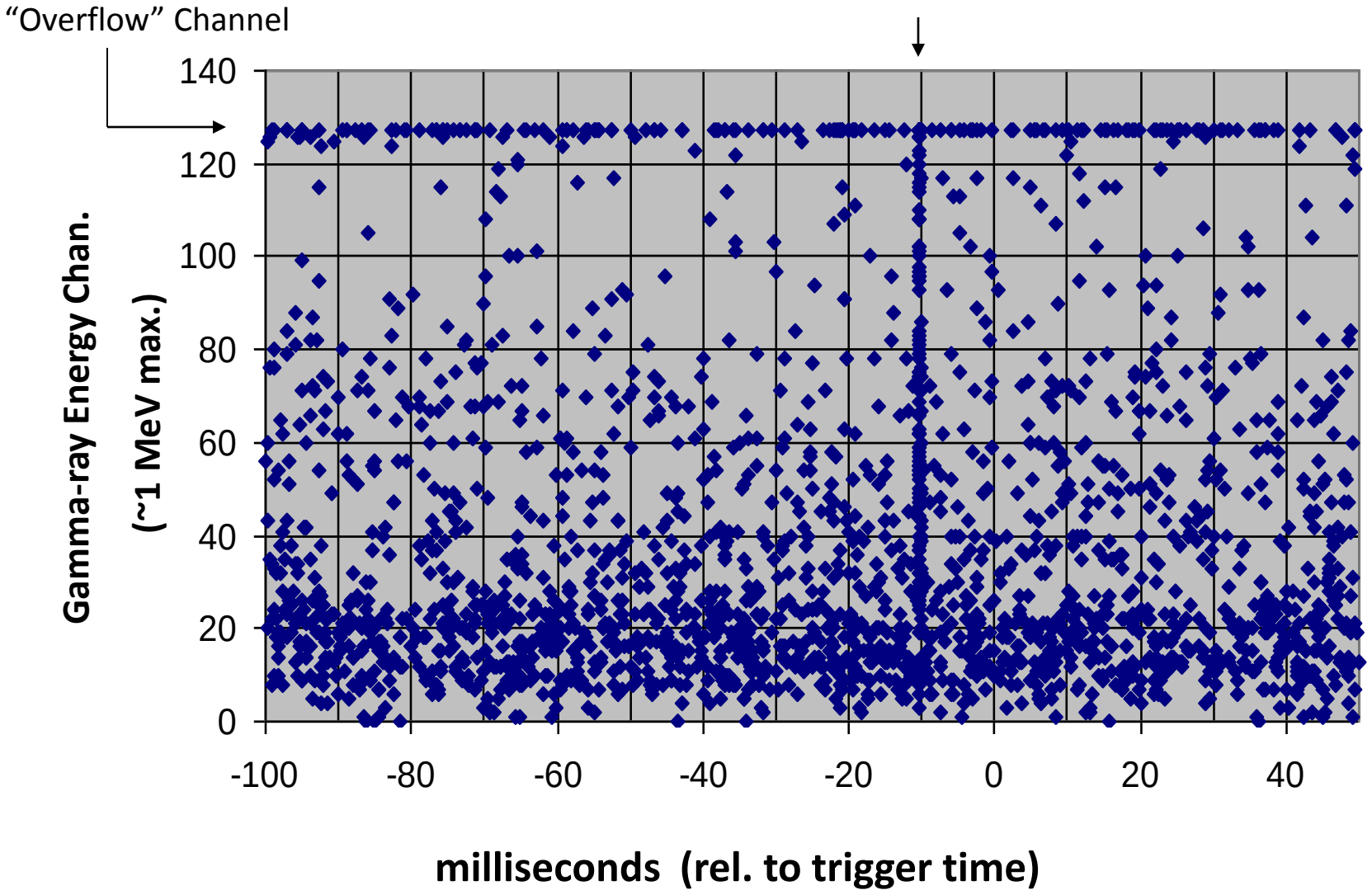
- Launched in 2008; Best Sensitivity to TGFs
- Good Spectral Resolution; Good Time Reolution

GBM

Detector Locations on the Fermi Spacecraft

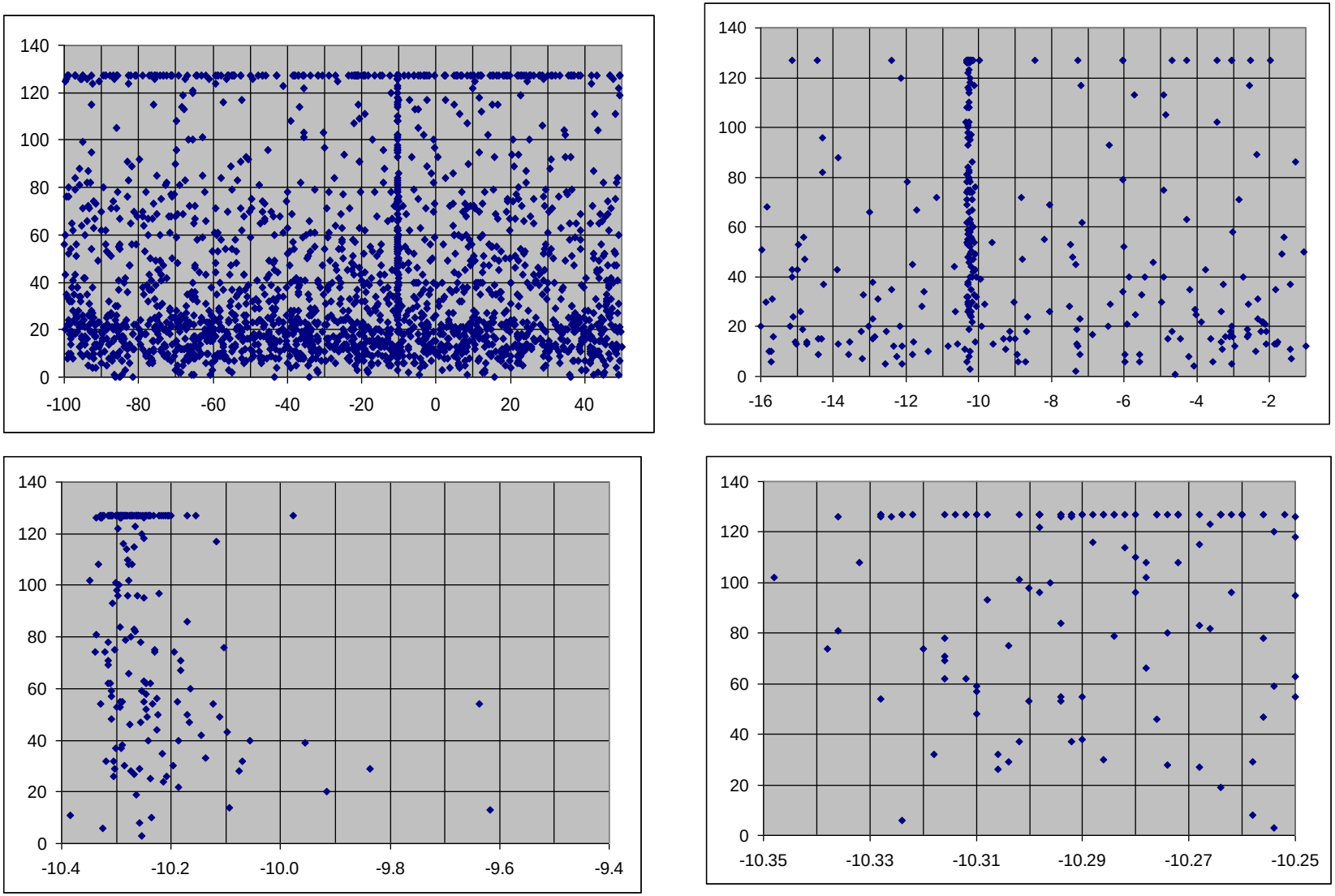


NaI Detectors – Showing Background & TGF (at 10ms)



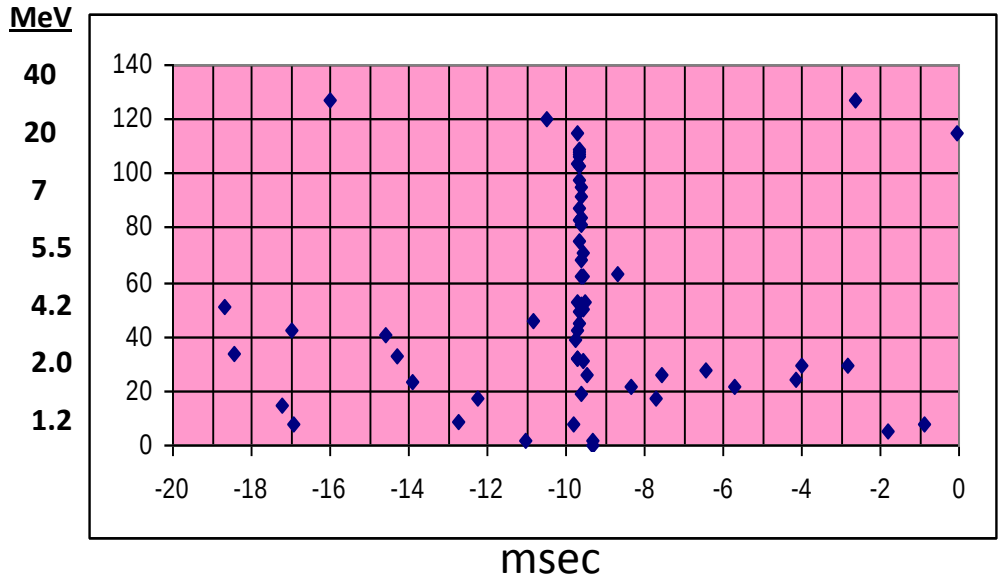
TGF #7, Nov. 23, 2008 Fermi – GBM

NaI Detectors (12, combined)



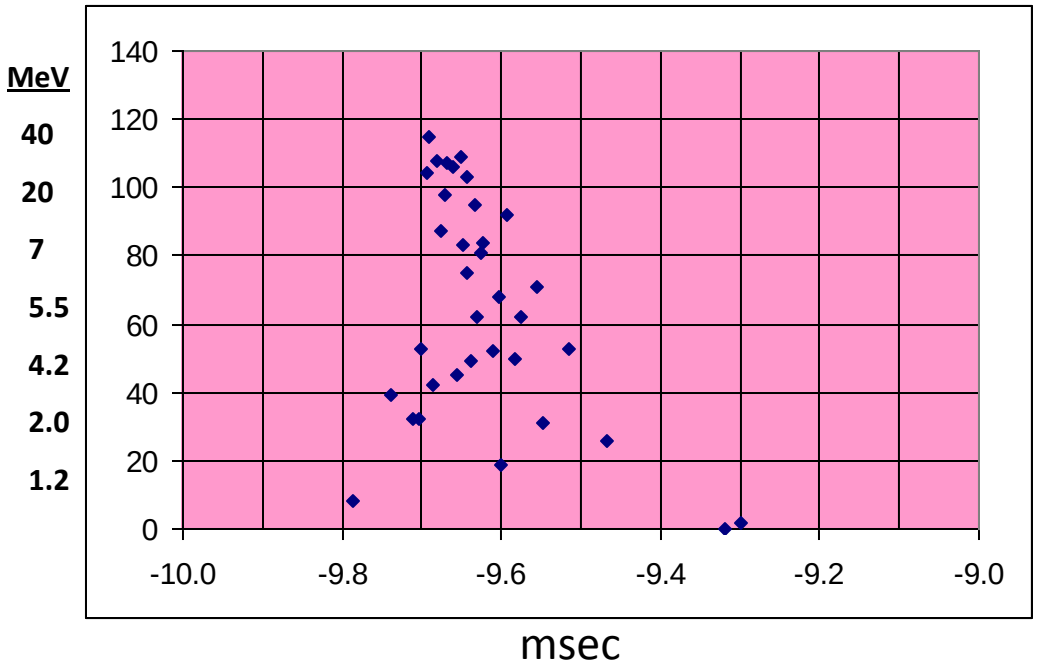
TGF_#5

BGO 0

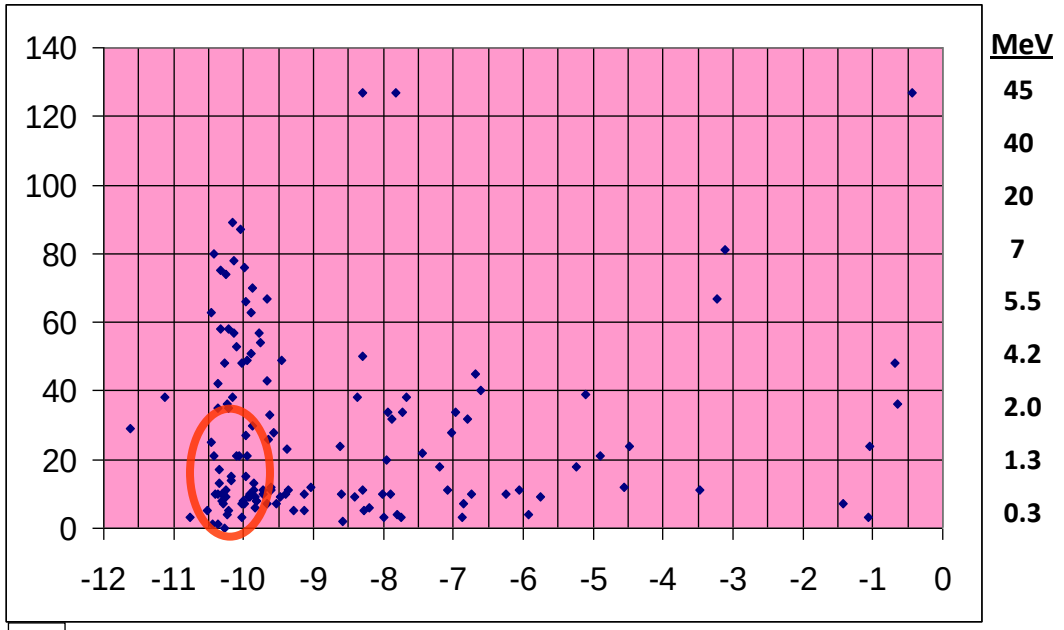


Duration

~150 microsec



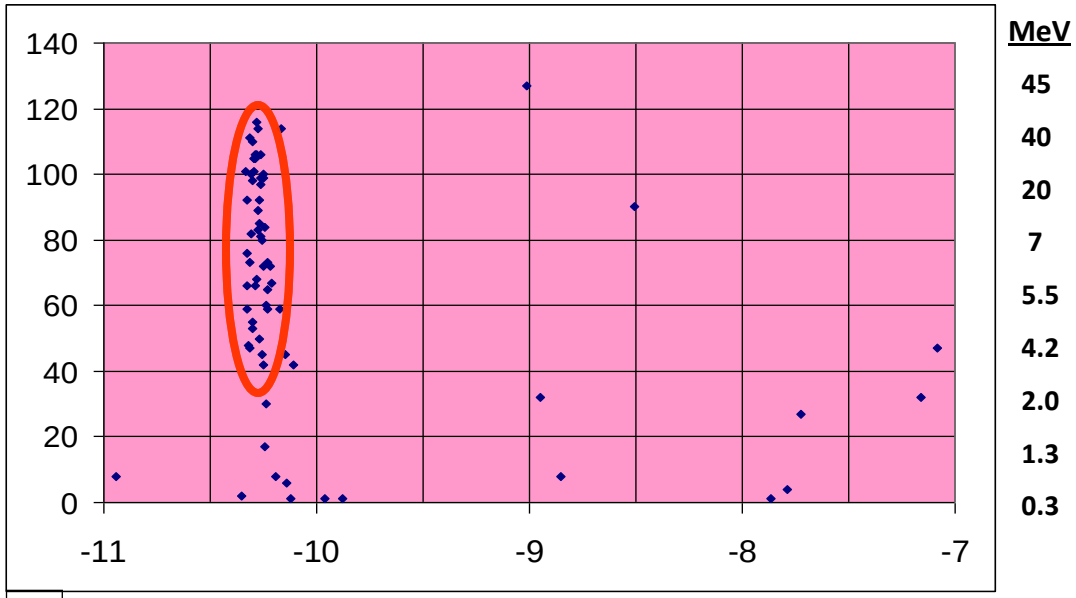
Spectral Differences



1

TGF #1:

- Low energies dominate



7

TGF #7:

- High energies dominate

What Causes them?

Ans.: *Relativistic Runaway Electron Avalanche (RREA)*

Early work (1992):

RREA Model of

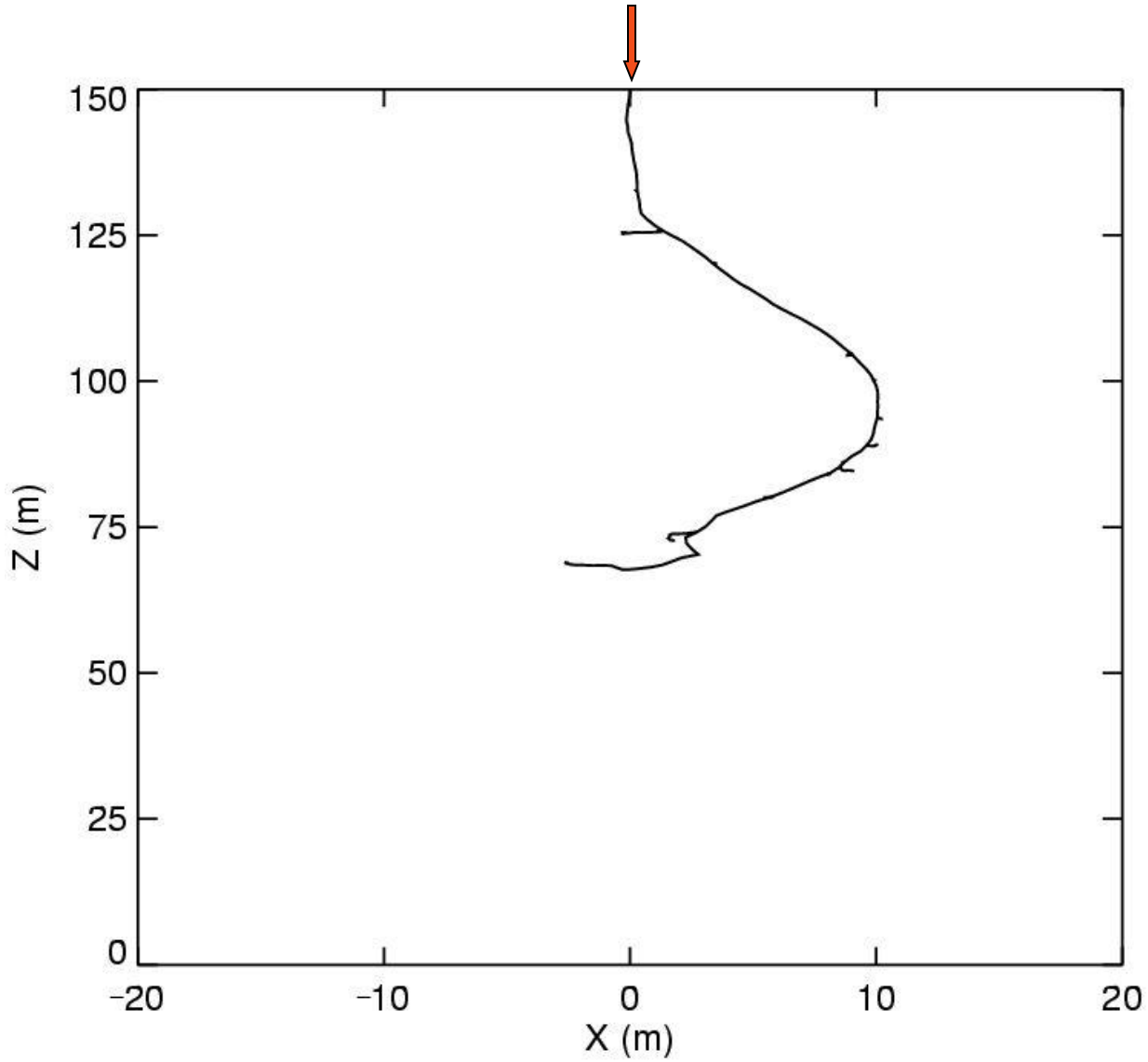
Gurevich, Milikh & Roussel-Dupre

Recent Work:

Dwyer; Milikh; Babich; Stanford U. group

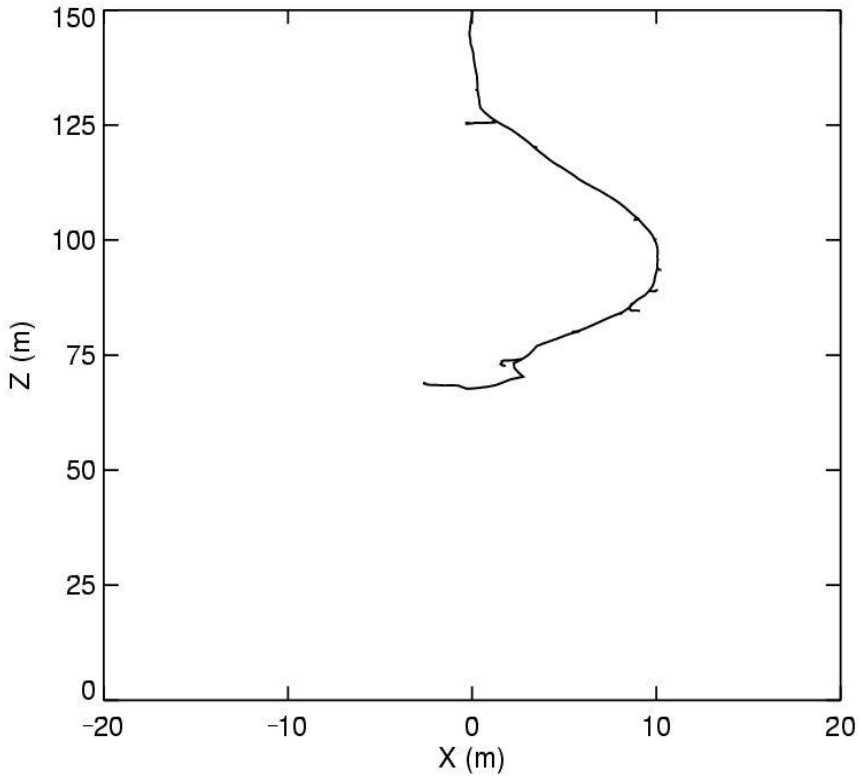
(Note: Very early work: C.T.R. Wilson -1925! – Critical Electric Field)

25 MeV electron moving through air at 1 atm

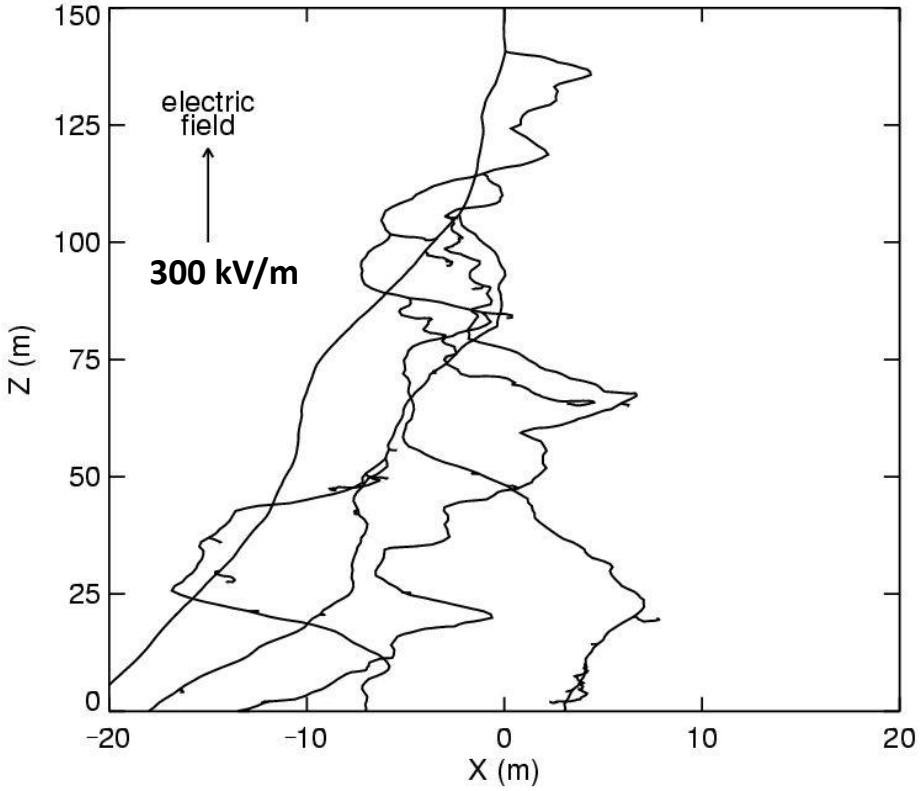


25 MeV electron moving through air at 1 atm

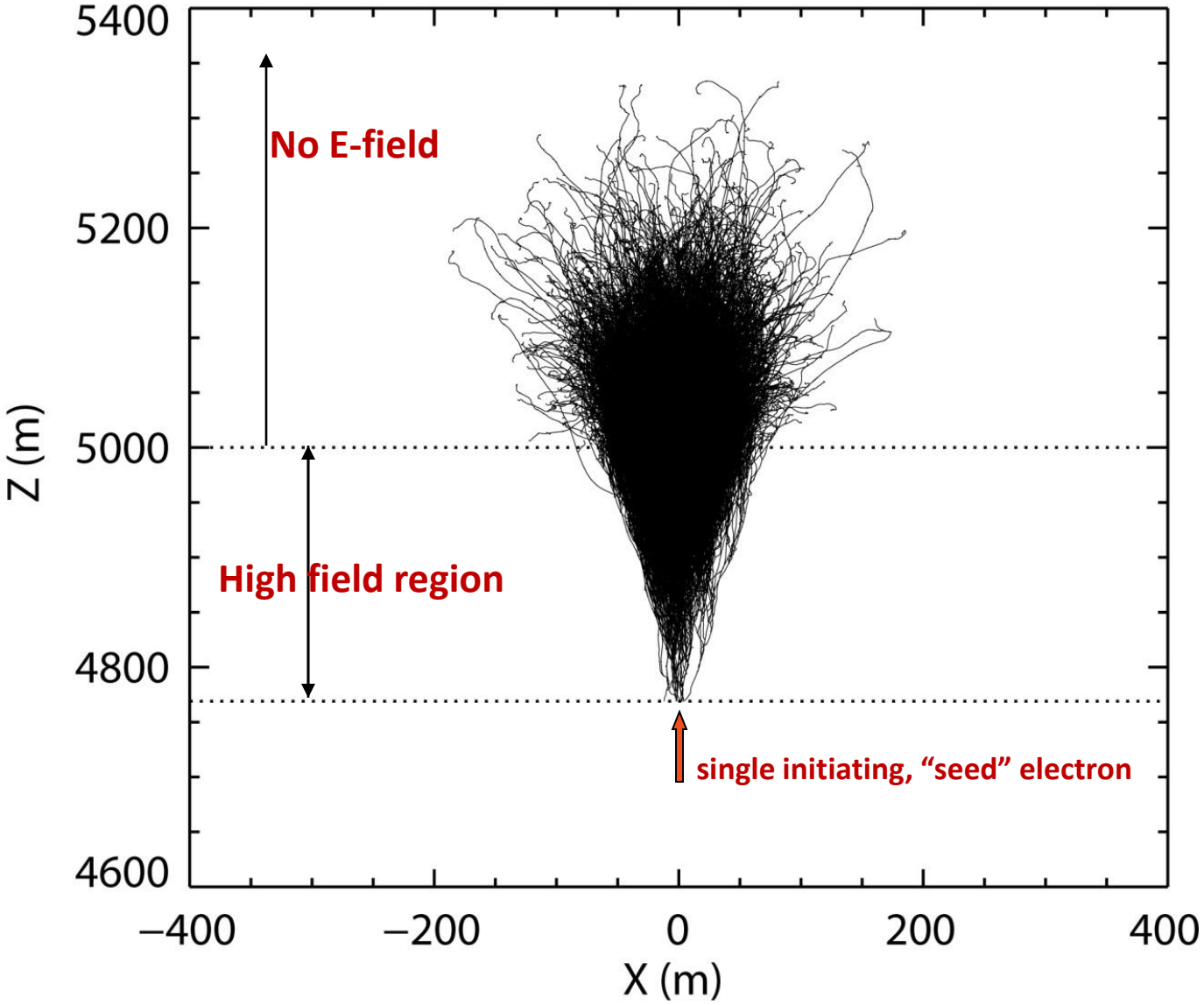
No electric field



In a 300 kV/m electric field

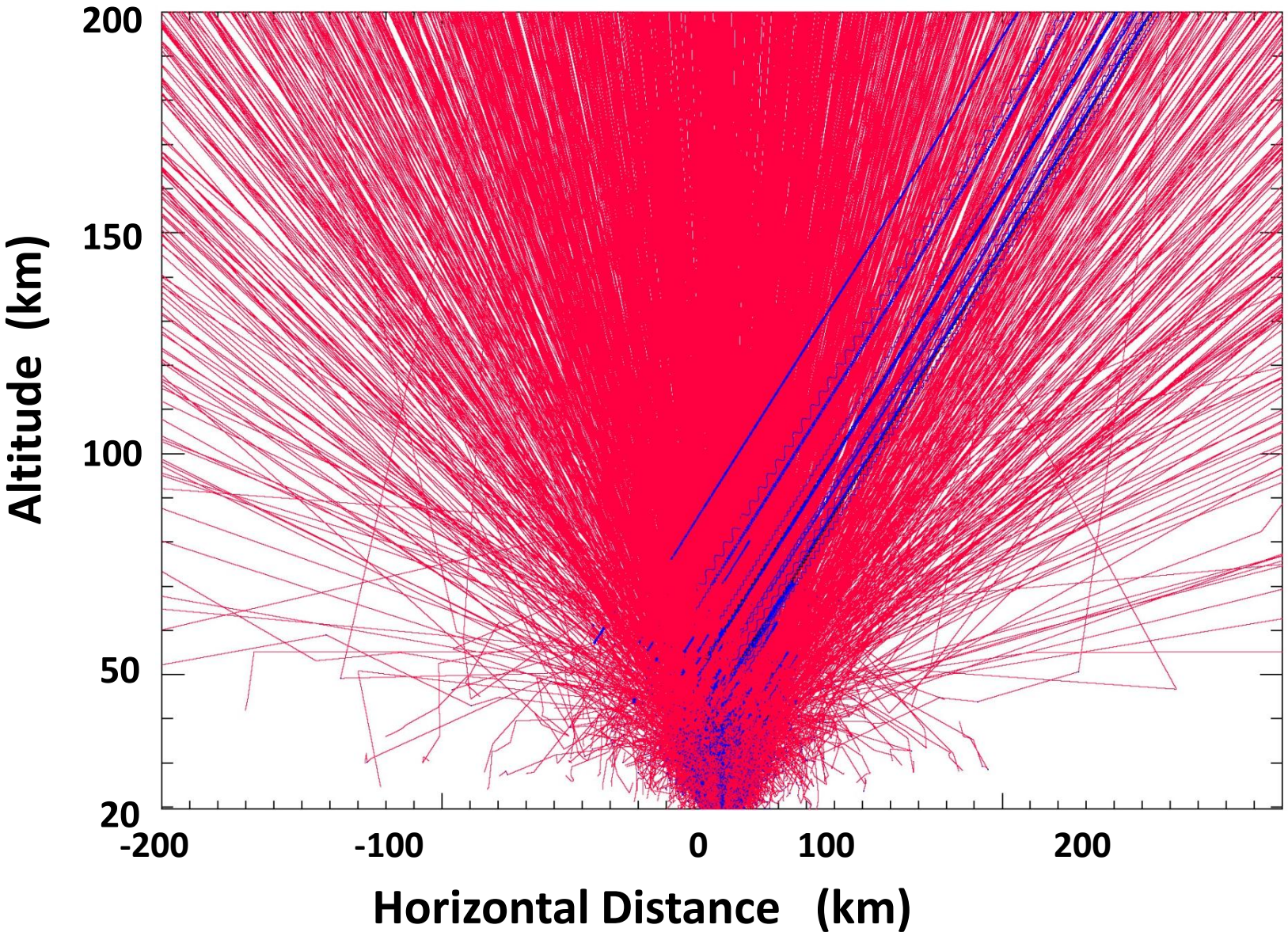


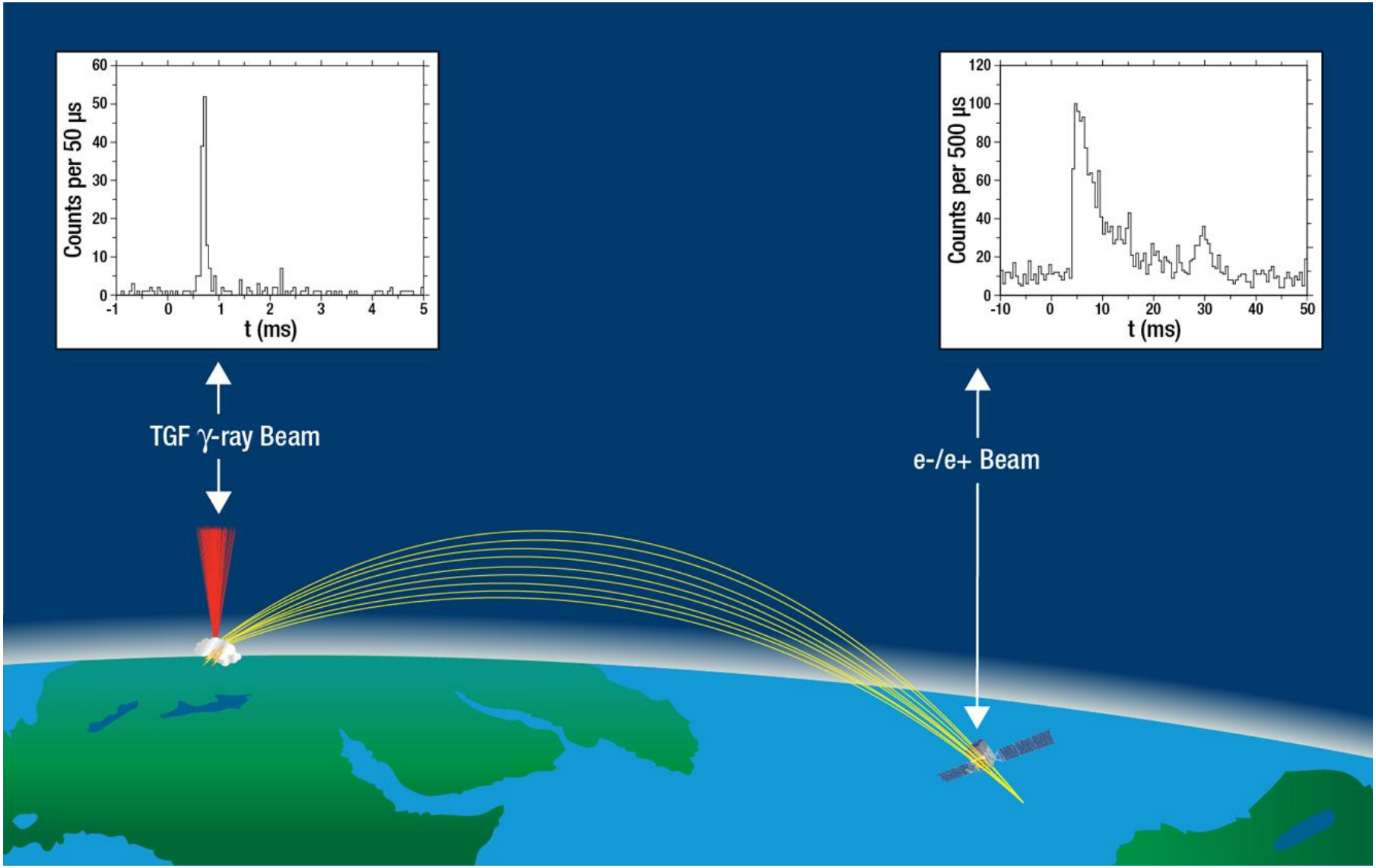
Monte Carlo simulation showing runaway electron trajectories, inside a thundercloud at 5 km altitude



TGF Simulation

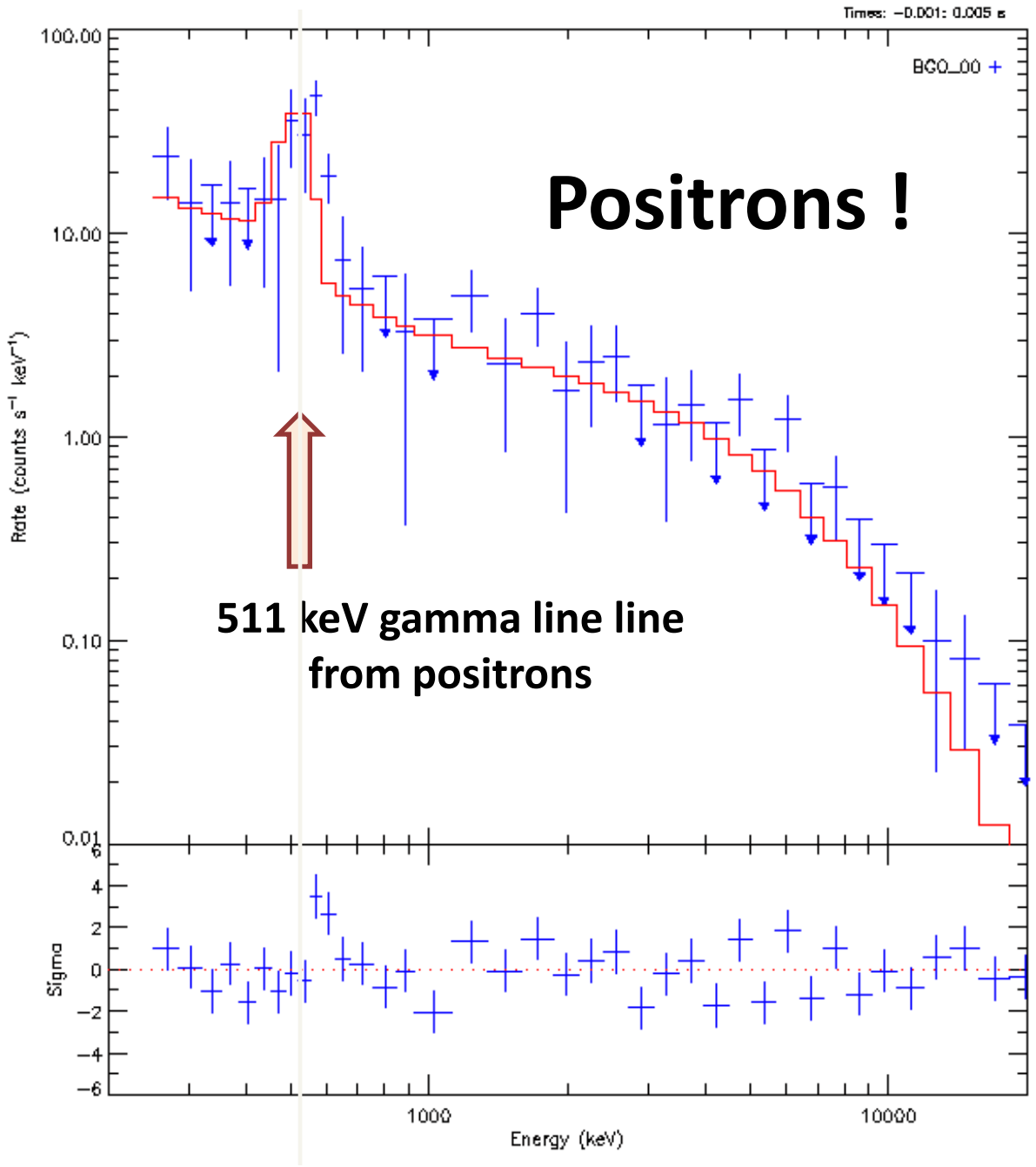
Gamma-rays (red); Electrons (blue)



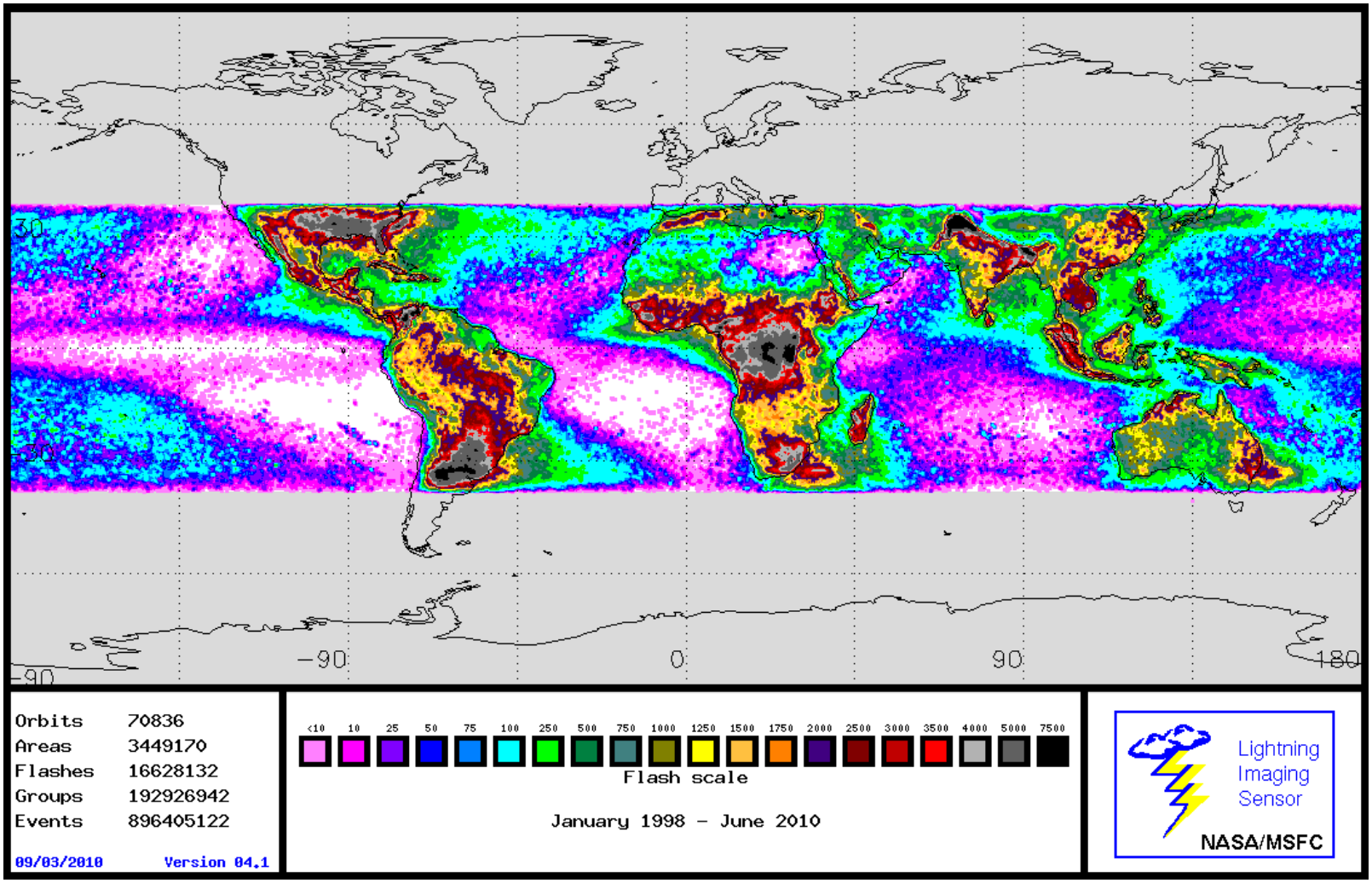


TGF: Gamma-ray Beam **Electron/positron beam**

Spectrum of TGF

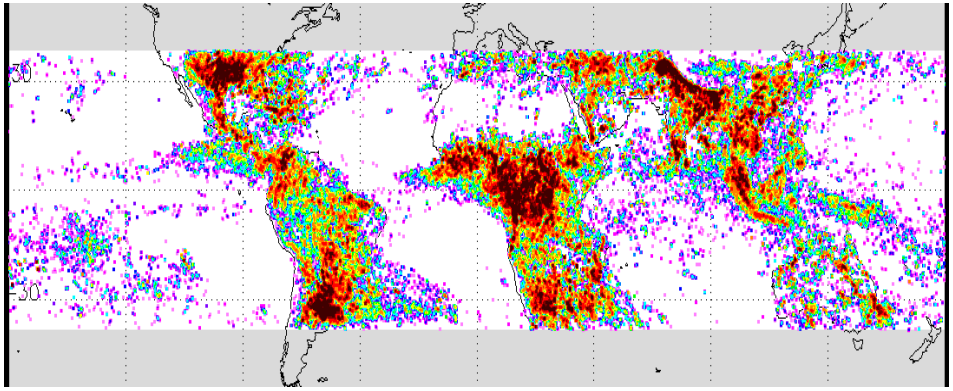


Global Thunderstorm Regions

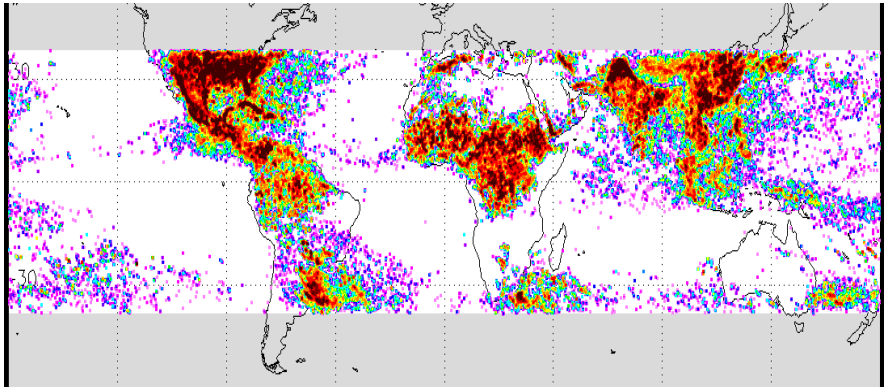


Global Lightning – by Season

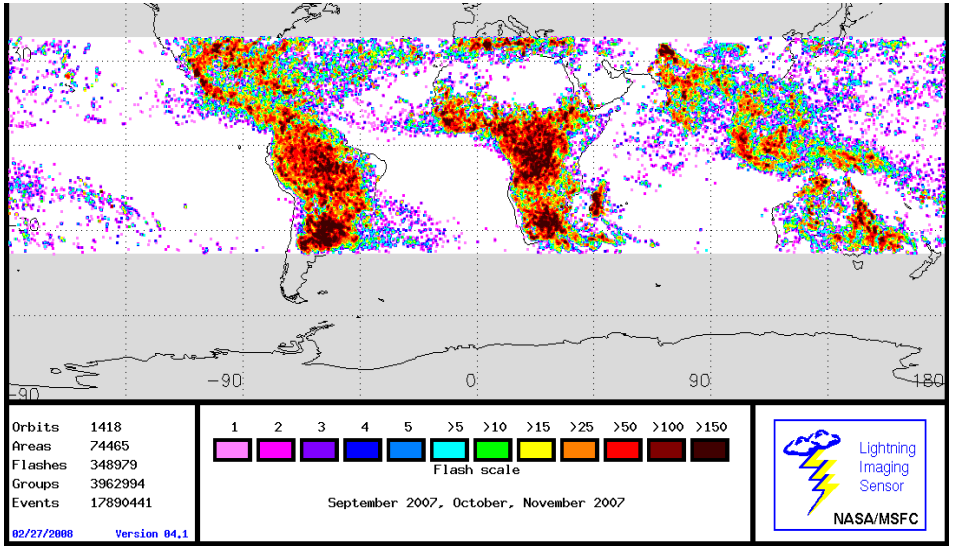
(NASA/MSFC - LIS data, 2007)



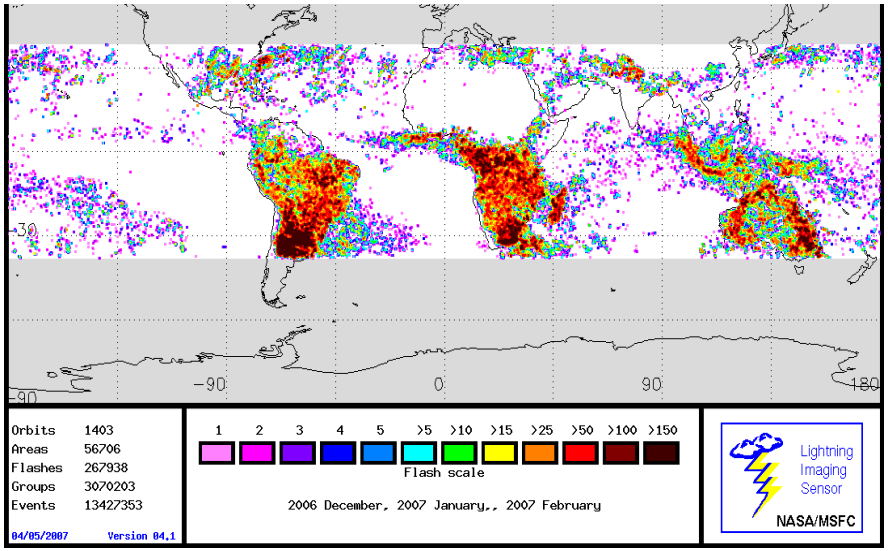
Spring



Summer

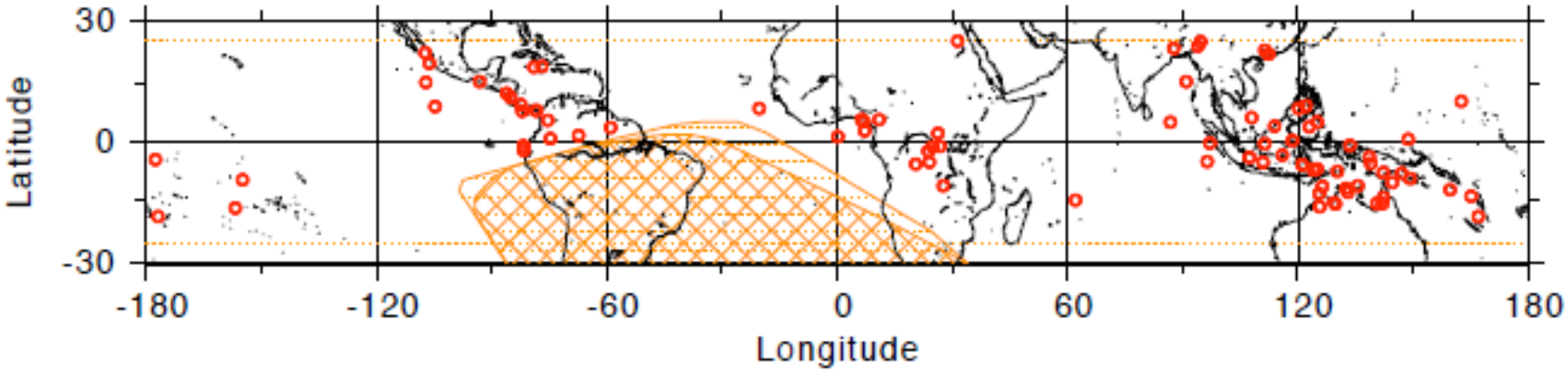


Fall



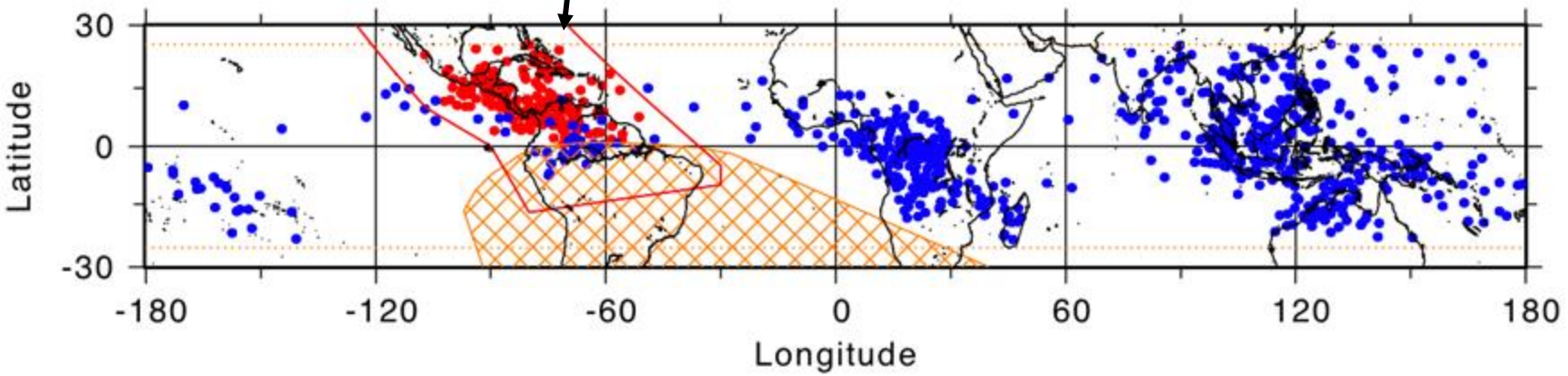
Winter

Fermi – GBM
Locations of 85 TGFs



New Capability: "Un-triggered" TGFs

"America's Region"



● - RHESSI TGFs

● - RHESSI TGFs, May-November

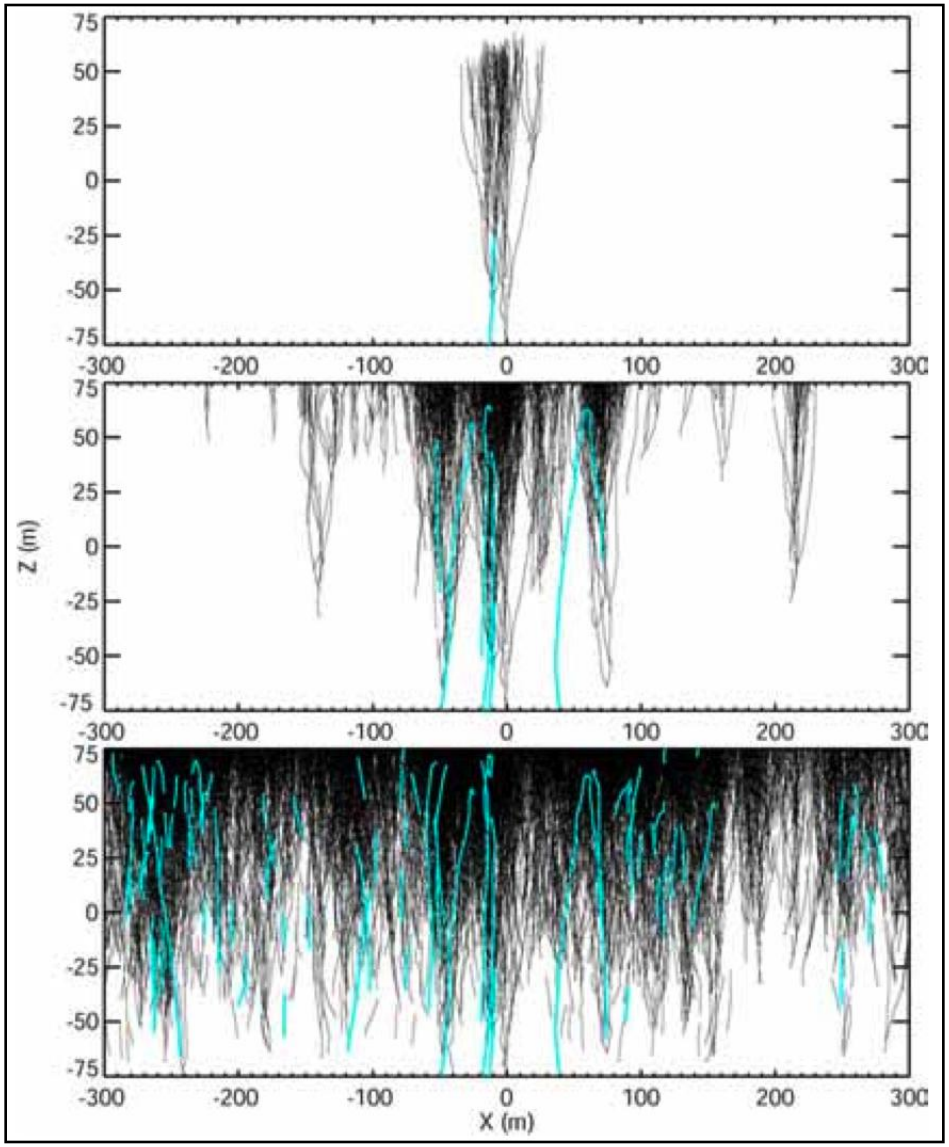
~2 TGFs per day in "America's" Region - untriggered TGFs

Positron & gamma-ray feedback

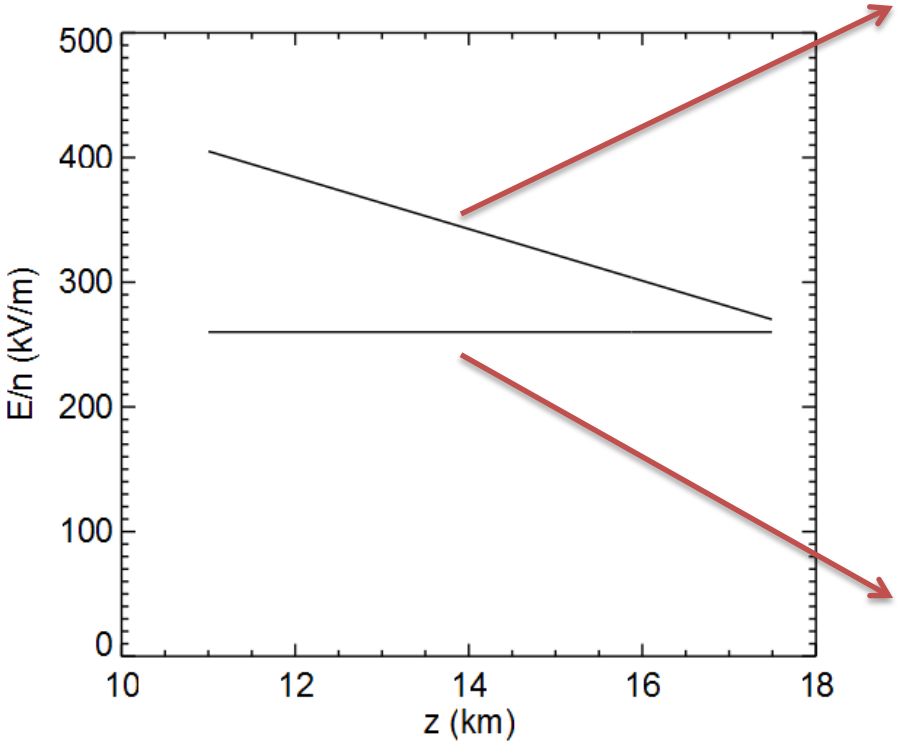
Feedback limits the number of avalanche lengths possible;

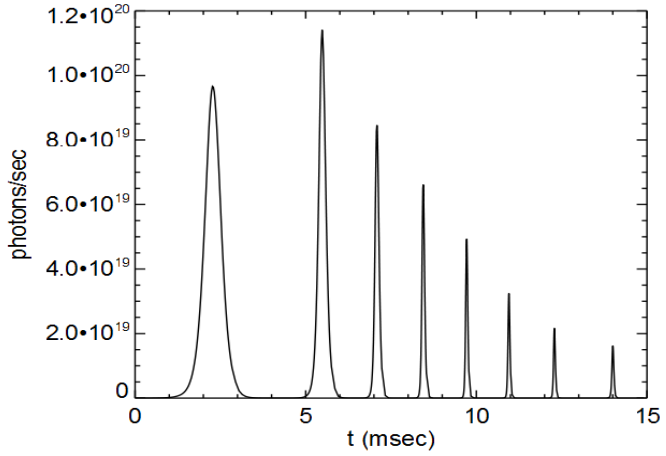
But feedback allows true discharge even with only a few avalanche lengths

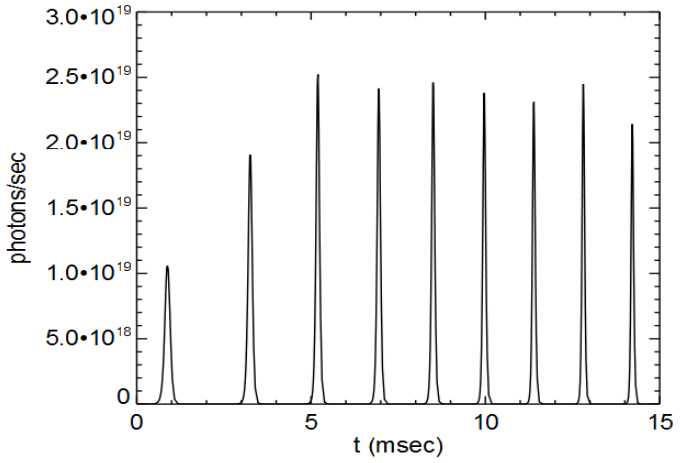
Feedback predicts correct TGF duration and approximate luminosity (Dwyer 2008)



Electric field configurations and pulse profiles

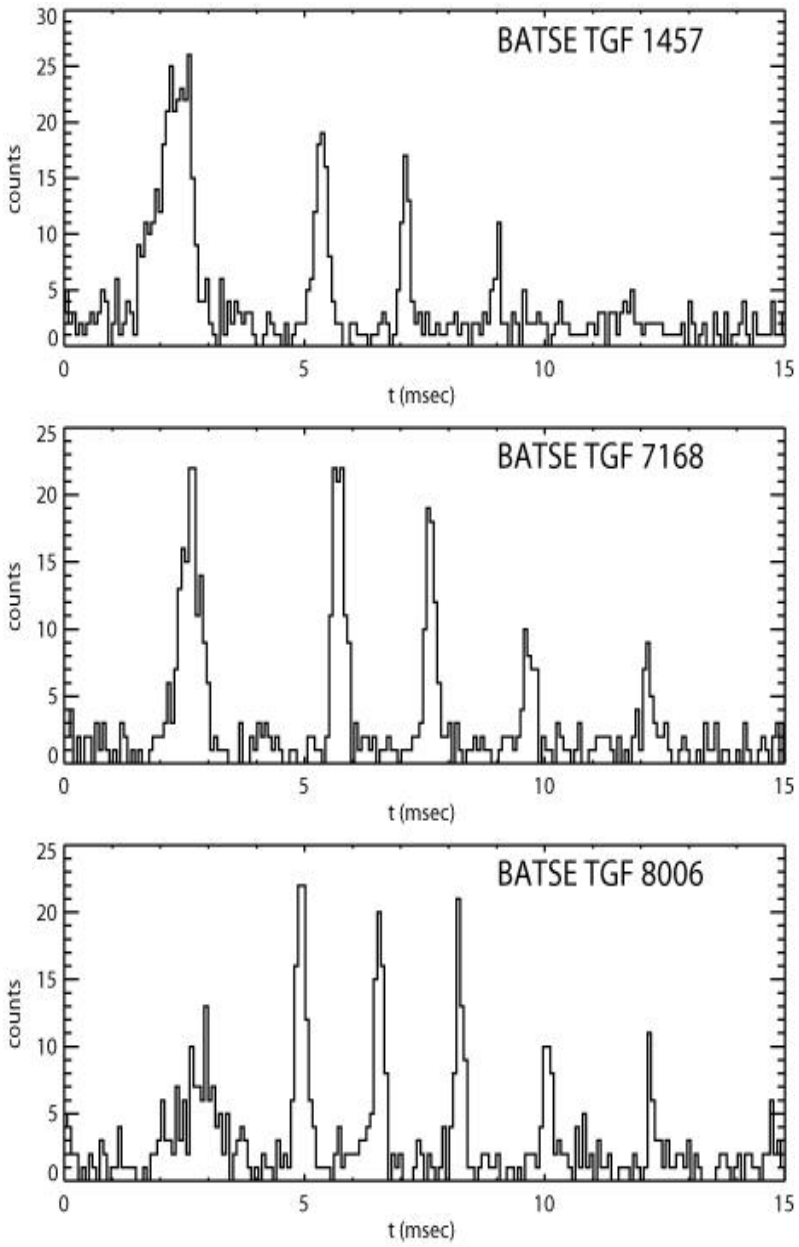




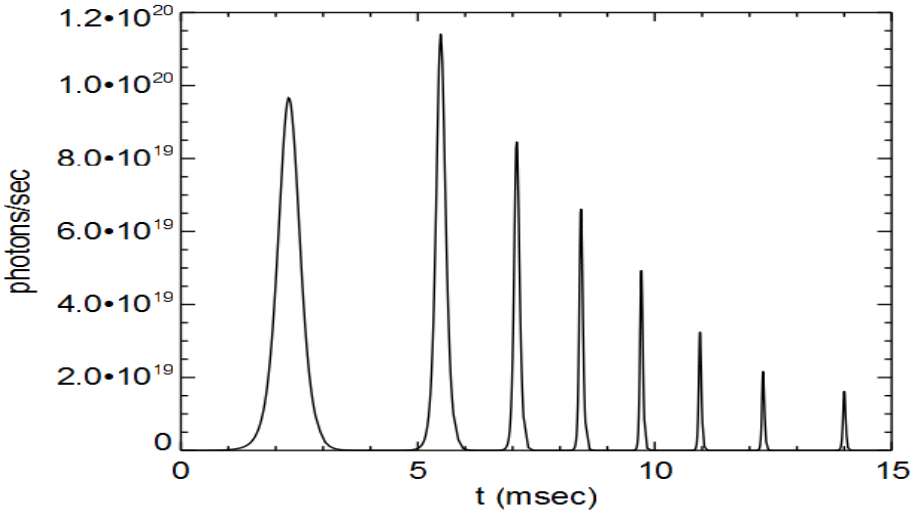


More multi-pulsed TGFs

CGRO/BATSE TGFs

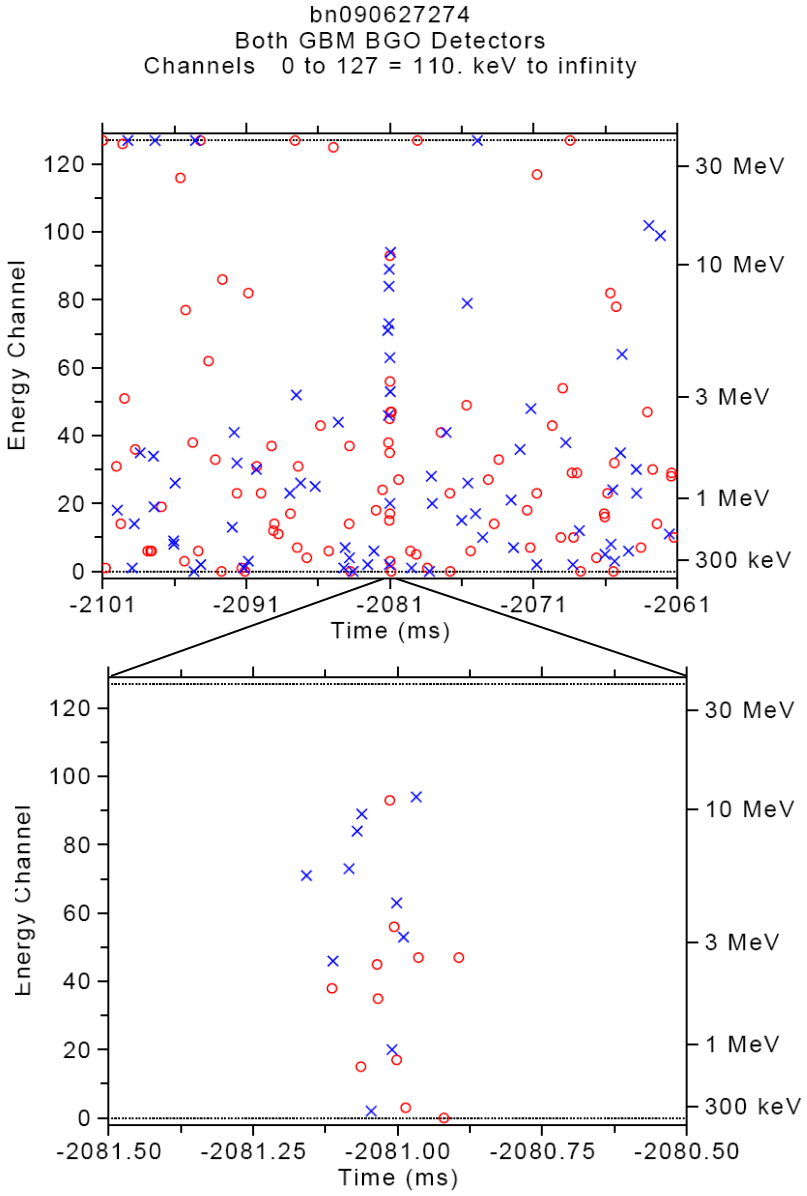


Model result

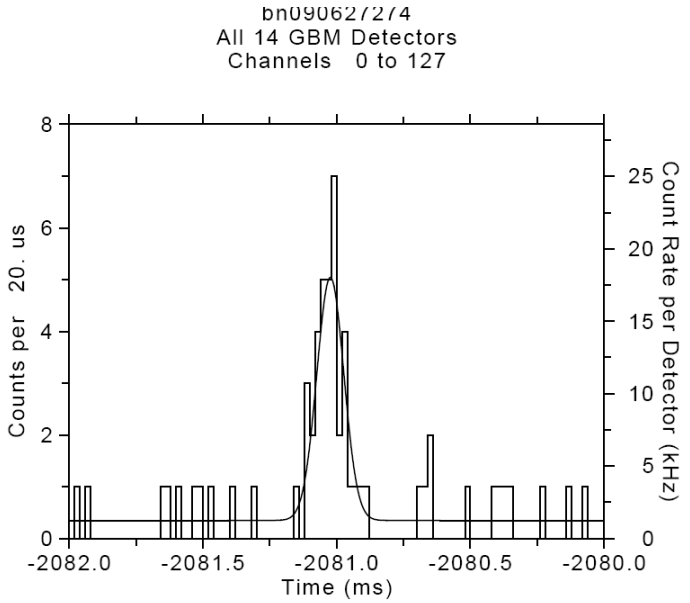


Dwyer 2011

First look at a GBM an Un-triggered TGF



Binned Data 20µs/bin



TGF

Full-Width: ~0.25ms

Total cts above bkgnd: ~35 cts

Peak ct. rate: ~20kcps

(Spectrum appears similar to strong TGFs)

“Gigantic Blue Jets” – Related to TGFs?

V. Pasco/Penn. State, 2008

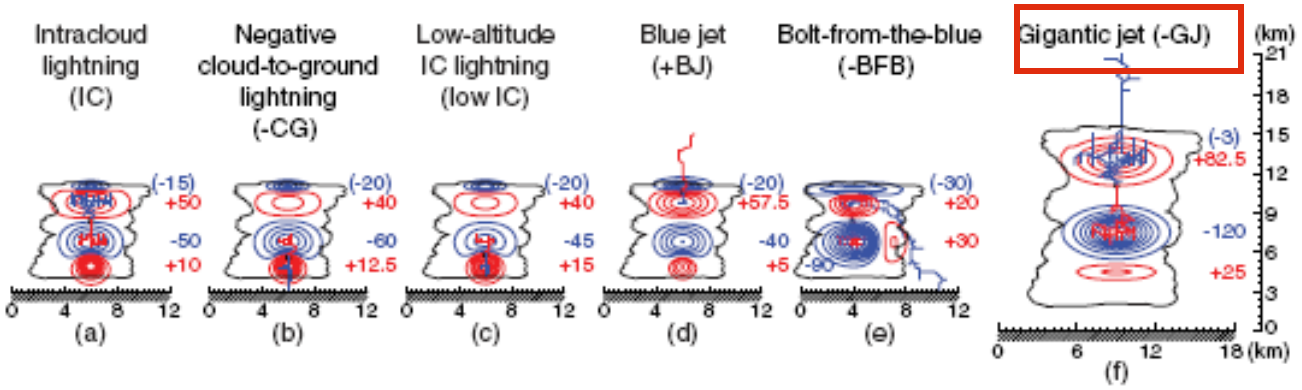


Figure 4. Simulated discharges illustrating the different known and postulated lightning types in a normally electrified storm [65]. (*a*)–(*f*) The contours and numbers with signs indicate negative and positive charge regions and charge amounts (in C), each assumed to have a Gaussian spatial distribution. A partially analogous set of discharges occurs or would be predicted to occur in storms having inverted electrical structures (see figure S5 in [65, Supplementary Information]). Reprinted from [65] by permission from *Nature Geoscience*.

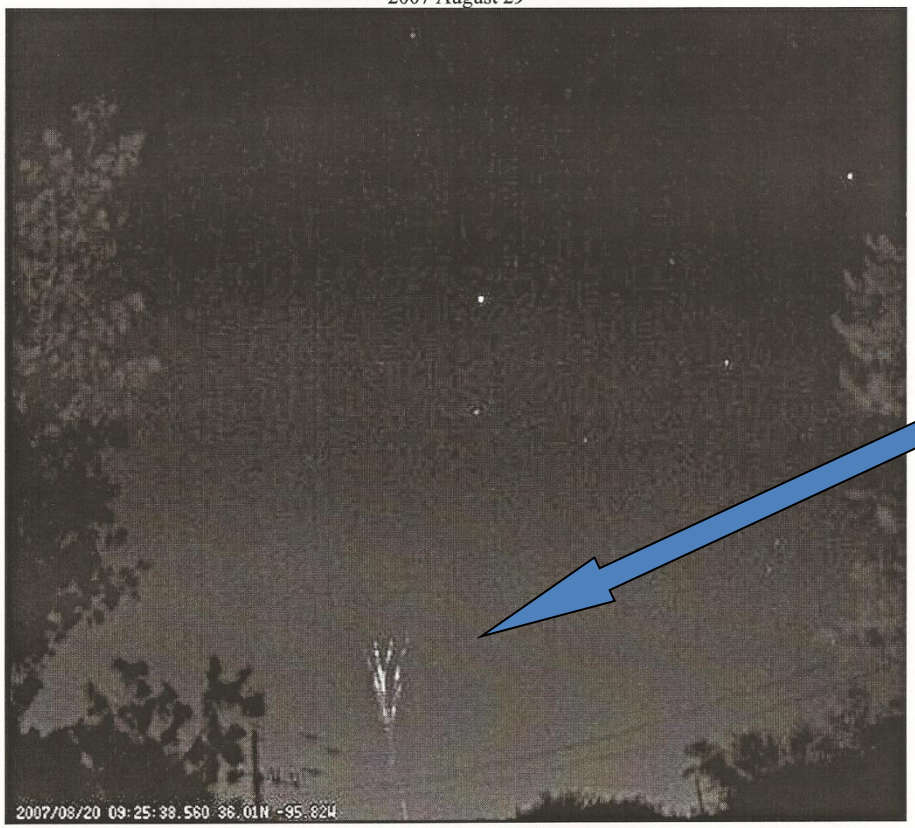
Aircraft Cruising Alt.

~10-12 km

Astronomy Picture of the Day

Discover the cosmos! Each day a different image or photograph of our fascinating universe is featured, along with a brief explanation written by a professional astronomer.

2007 August 29



Gigantic Jets Over Oklahoma
Credit: Richard Smedley

Explanation: Have you ever seen a gigantic jet? They are extremely rare but tremendously powerful. Gigantic jets are a newly discovered type of lightning discharge between some thunderstorms and the Earth's ionosphere high above them. Pictured above is one such jet caught by accident by a meteor camera in Oklahoma, USA. The gigantic jet, at the lower left, traversed perhaps 70 kilometers in just under one second. Clicking on the image will bring up a movie in many browsers, also visible here. Gigantic jets are much different from regular cloud-to-cloud and cloud-to-ground lightning. The bottoms

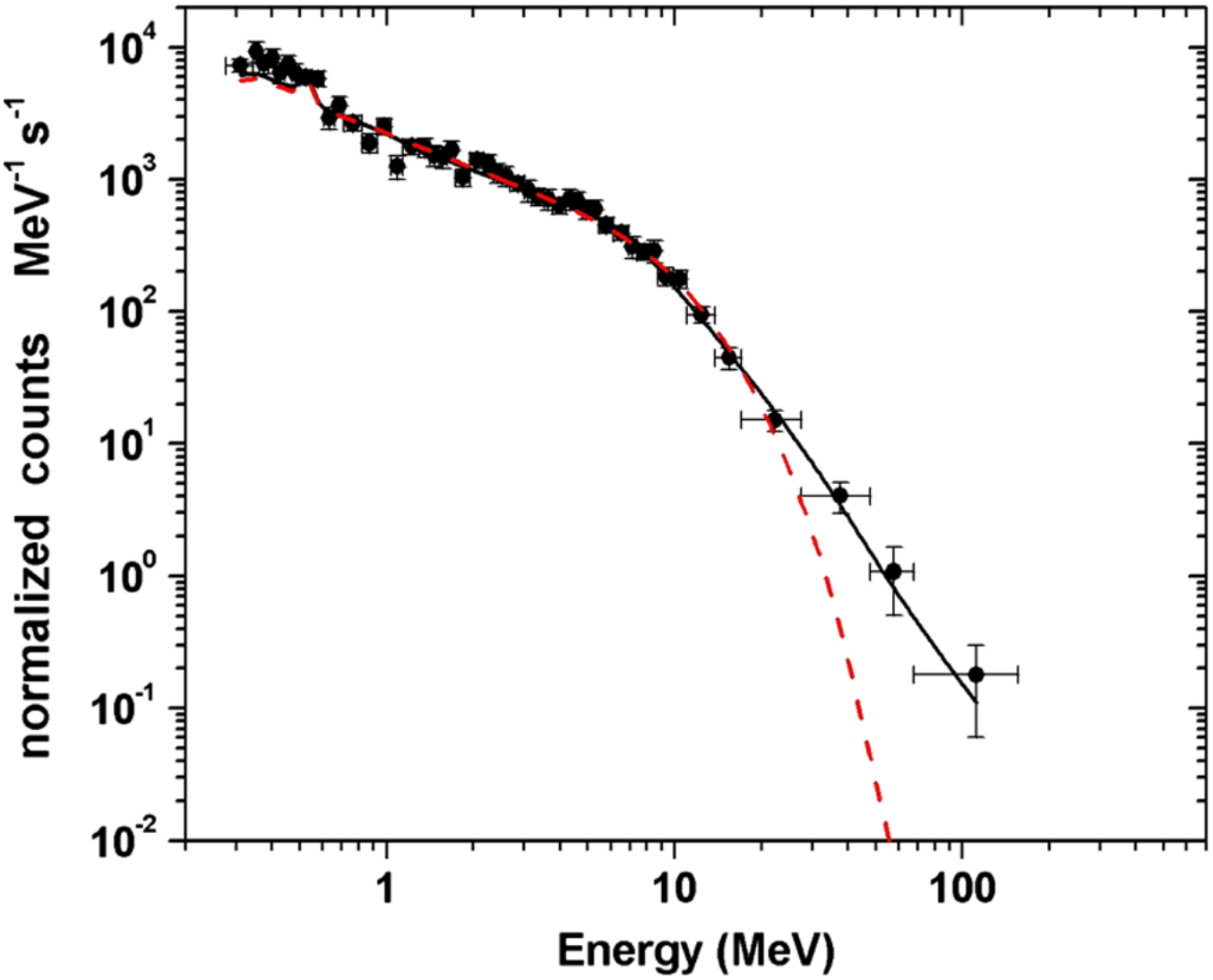
Upward moving "Blue Jet" from cloud-top to ionosphere

TGFs

Questions for Atmospheric Research:

- **At what altitude are they produced ?**
- **Beaming properties?**
- **What is the intensity distribution of TGFs ?**
- **Are TGFs related to Gigantic Blue Jets ?**
- **Are TGFs dangerous to airline crew and passengers?**

“AGILE”
Spectrum of a TGF at High Energies



10th **AGILE** Science Workshop

ESA-ESRIN (Frascati), April 18, 2012

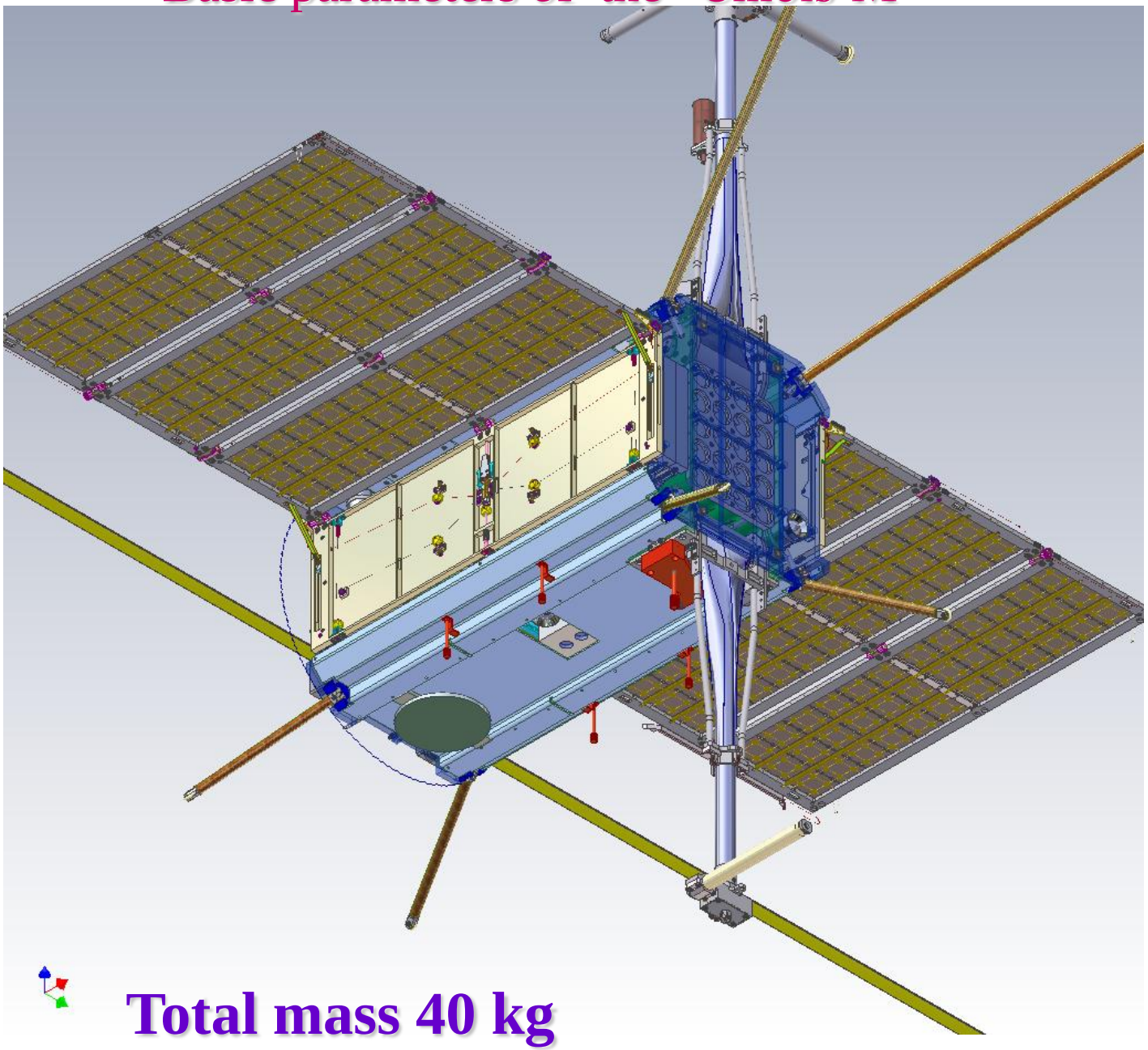
Lightning, Terrestrial Gamma-Ray Flashes, and Meteorology

Scientific Organizing Committee (SOC)

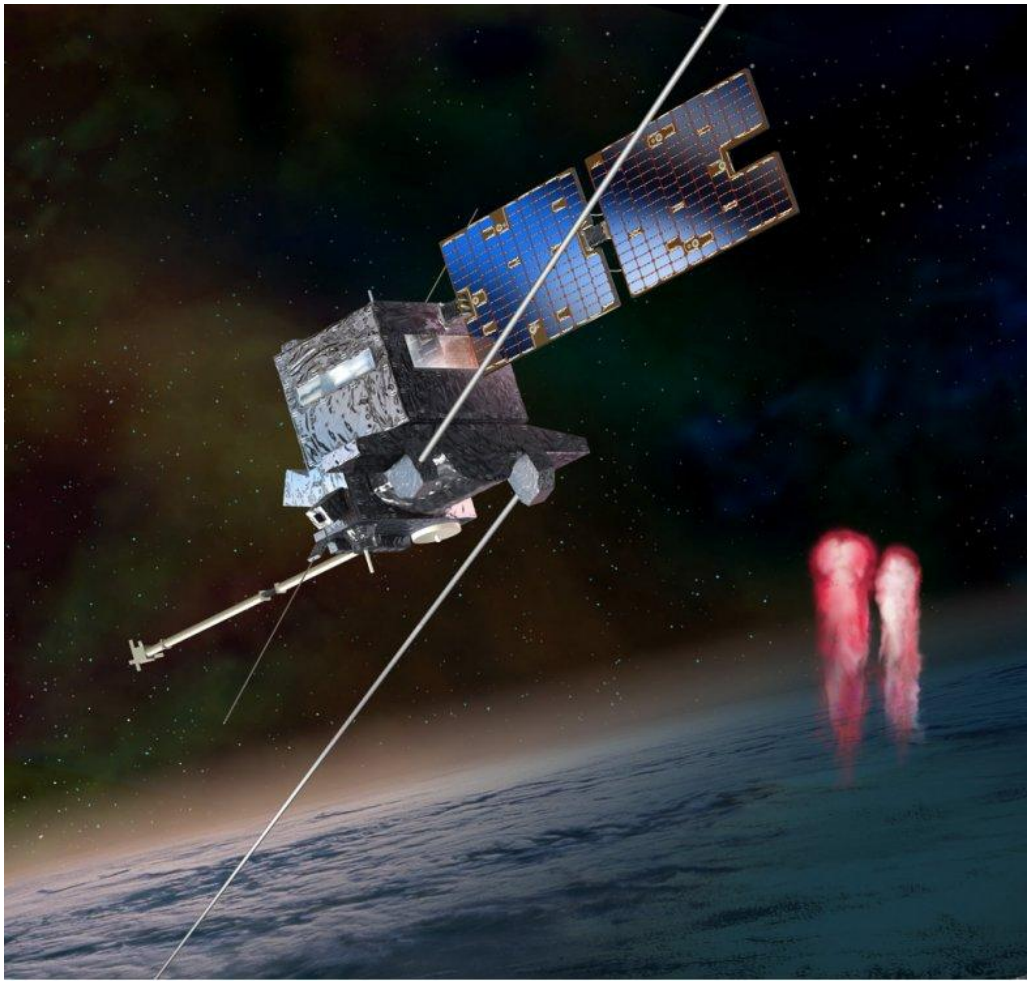
Future Spacecraft to Study TGFs:

- **Firefly – NSF cubesat; GSFC; Siena Coll.**
- **ASIM – on ISS; ESA, led by Danish**
- **TIRANIS – French & others**
- **CHIBIS-M – Russian (IKI) & others**

Basic parameters of the “Chibis-M”

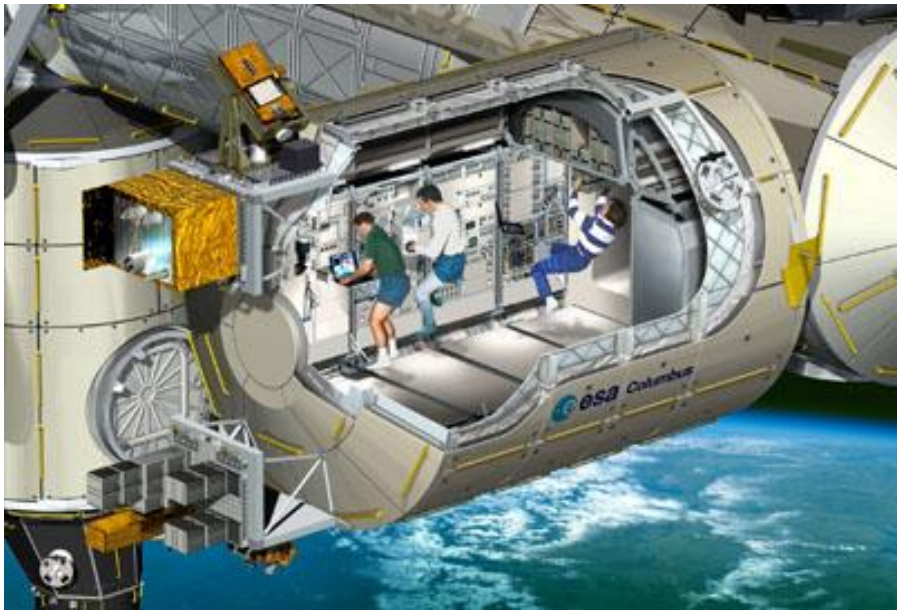


Total mass 40 kg



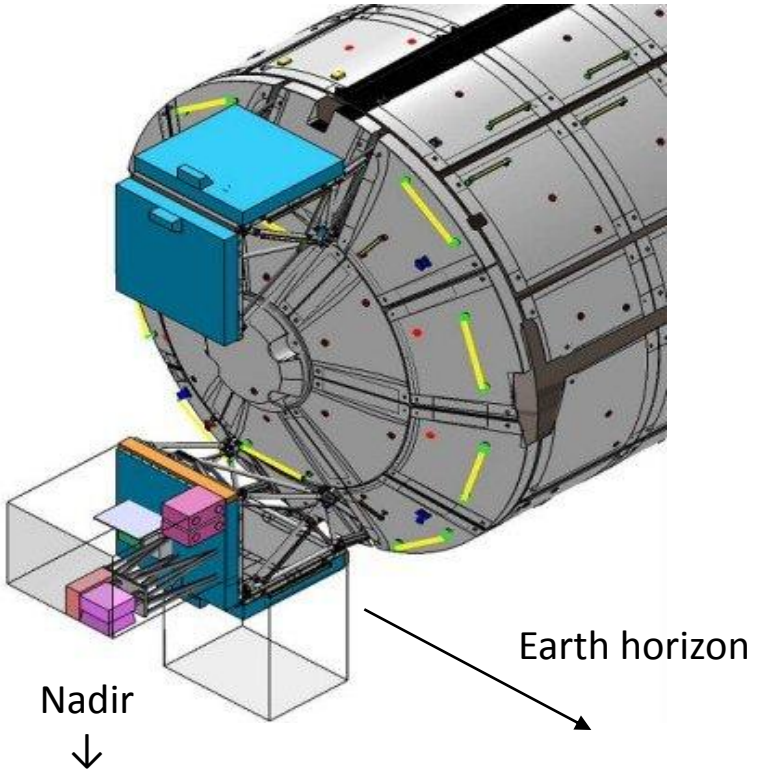
TIRANUS Satellite – France

Under development; planned for launch 2013



The Columbus model
on Node-2 of the ISS

The University of Valencia is
part of the phase-B study of
a proposed imager and
spectrometer instrument
MXGS
to be mounted on the
Columbus module of ISS



The End